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The Invention Issue

- Steve Wozniak's tracking device for kids and pets
- The battle to reinvent audio
- Microsoft's magic pen
- Why big companies can't invent

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"You can't **outdevelop** Microsoft, but you can ***outinvent*** them."
NATHAN MYHRVOLD

5 KILLER PATENTS P.66

PLUS:
Global invention map

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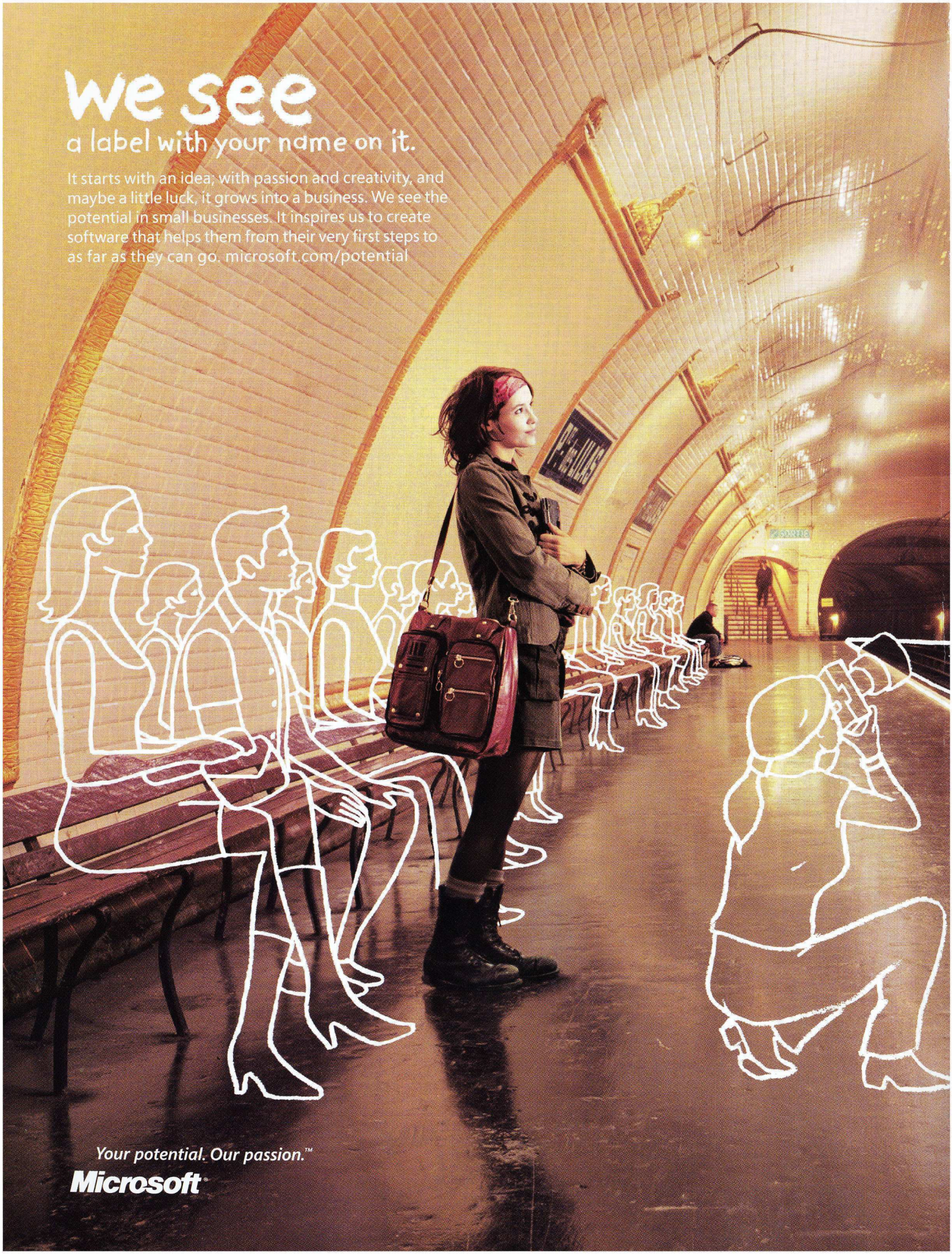
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Cover photograph by Fredrik Broden


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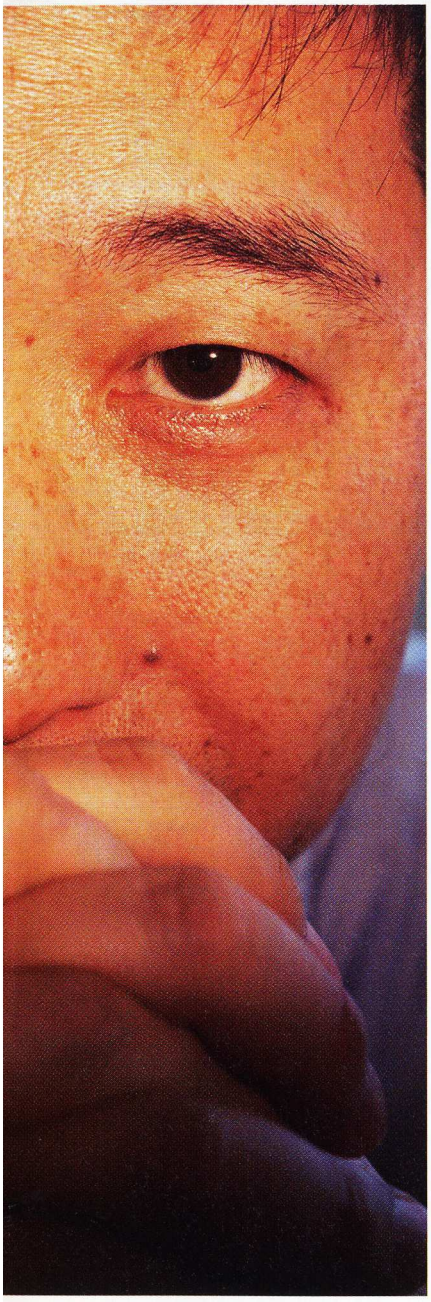
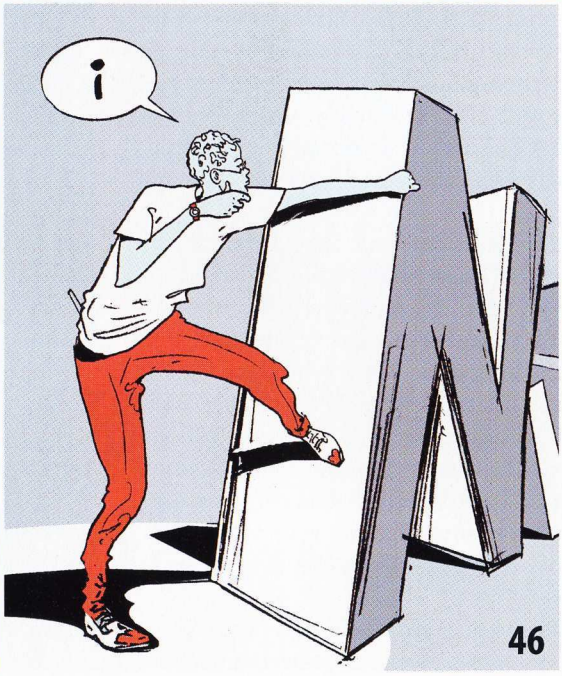
DEPARTMENTS

Technology Review
Volume 107, Number 4
May 2004

"Invention is the new software."
—*Nathan Myhrvold, p. 35*





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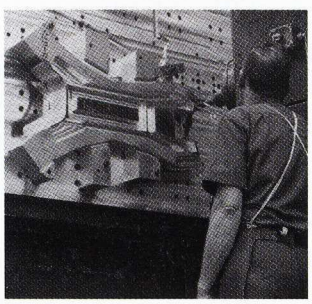

Reinventing Invention

THE BRITISH PHILOSOPHER ALFRED NORTH Whitehead proclaimed that "the greatest invention of the 19th century was the invention of the method of invention." Whitehead was talking about the systematic, scientific method that led to great research universities, individual inventors such as Thomas Edison, and the major industrial research-and-development labs that have dominated patenting for decades. ■ Is the beginning of the 21st century witnessing the invention of a new method of invention?

If the people central to this special issue are right, it is. So we set out to explore their ideas—as well as some of the fruits of invention today. The stage is set in "Sparking the Fire of Invention" *(p. 32)*, by contributing writer Evan I. Schwartz. Schwartz, whose book *Juice: The Creative Fuel Driving Today's World-Class Inventors* is due out this fall, helped conceive this issue. He lays out the argument that we're entering a new age, shining the spotlight on former Microsoft chief technology officer Nathan Myhrvold and his new enterprise Invention Science, which is assembling technologists from around the world and turning them loose against his former employer and other corporations.

Myhrvold's ideas are corroborated by legendary inventor Ray Kurzweil, who details his own perspective on invention today in "Kurzweil's Rules of Invention" *(p. 46)*. Chiming in from another perspective is venture capitalist Howard Anderson, who says big corporations are almost incapable of making meaningful inventions *("Why Big Companies Can't Invent," p. 56)*. Rounding out the package are profiles of inventors who epitomize the current spirit of technical creativity. We look at Apple Computer cofounder Steve Wozniak and his startup, Wheels of Zeus *(p. 42)*; the competition to produce a revolution in audio between prolific inventor Elwood "Woody" Norris and young psychoacoustics expert Joseph Pompei *(p. 50)*; and Jian Wang of Microsoft's Beijing lab, who led the invention of a pen that captures whatever you write in digital form *(p. 60)*. And for an inspiring story of a 51-year-old inventor and mother of five, check out Joe Chung's column *(p. 26)*.

Such a focus on invention may seem anachronistic. After all, the prevailing dogma of the last several decades has been that the real value to business and society comes from the bigger, more important process called innovation. Ethernet inventor Bob Metcalfe, in this very magazine, once wrote an article entitled "Invention Is a Flower, Innovation Is a Weed" *(*TR *November/December 1999)*—pointing out the difference between merely creating a great new thing and doing the development, manufacturing, and marketing necessary for it to have a real impact. Or just consult columnist Michael Schrage. There's a reason, Schrage writes on page 17, that "*Technology Review* is MIT's Magazine of Innovation—not Invention."

To me, invention is a subset of innovation—just as relief pitching is a subset of baseball, and quality control is a subset of manufacturing. But think of the gains that come from focusing on and improving such subsets! It's the difference between, say, the Yankees and the Red Sox (of old), between Toyota and Detroit (perhaps of old). That's why I am intrigued by Myhrvold and others who are challenging prevailing views of invention. I can't wait to learn what happens. **Robert Buderi**

NEXT MONTH

Bill Gates's Beijing Bonanza
Want a peak into the future of computer science? Take a look inside Microsoft Research Asia, which is rapidly becoming one of the world's hotbeds of innovation.

Where's the Beef?
Following the outbreak of mad-cow disease in the United States and Canada, pressure is growing to more accurately track meat as it passes from farms to feed lots to slaughterhouses to supermarkets. But is current technology up to the job?

The Silicon Guinea Pig
The pharmaceutical industry spends millions developing drugs, only to see many of them fail once they're tested in animals or humans. New biochips containing live cells could give drugmakers a far cheaper and easier way to spot tomorrow's blockbusters.

Free Phone Calls
Sick of high international phone rates? The same renegade programmers who transformed online music swapping are now taking on Internet telephony. The result: free, easy-to-place phone calls to anywhere—using the Internet.

Demo: Holographic Video
New 3-D holographic videos will eventually change the way you see the world. For now, researchers will settle for transforming everything from medical imaging to military navigation.

Why IT Still Matters
Ethernet inventor, 3Com founder, and venture capitalist Robert Metcalfe debunks the contention that innovation in information technology no longer gives companies a competitive edge. Quite to the contrary, he argues, the strategic importance of IT continues to increase.

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product development
is about designing
high quality products
that never need recalls.

30,000ft.

25,000ft.

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IN SEARCH OF BETTER SEARCH

WADE ROUSH'S ARTICLE ("SEARCH beyond Google," *TR* March 2004) provides a well-composed, broad survey of search engine history and the competitive landscape. One surmises that Google has a sizeable lead but that new technology could crown a fresh champion. Interestingly, when I enter the term "search engine" on Google, google.com is ranked fourth. Maybe Google is even more aware of the competition than we realize.

Michael Ashley Schulman
Newport Beach, CA

IF MICROSOFT IS DEVELOPING SUCH flashy search technology, why are the search engines on its own websites so bad? I am a computer technician who spends a significant amount of time on various Microsoft sites looking for information, and using the "site:microsoft.com" parameter in Google returns far more relevant information than the Microsoft search does. Other difficulties include not being able to find specific software files in a search after they were downloaded from the Windows Update site and the apparent impossibility of locating software files by their file name. It also takes more clicks to run a search in Windows XP than in earlier versions of Windows. Given my difficulties with their current search technologies, I wouldn't trust Microsoft's future ones any farther than I could toss Bill Gates—and that's not far.

Marc Erickson
Edmonton, Alberta

"If Microsoft is developing such flashy search technology, why are the search engines on its own websites so bad?"

A NET PHONE DEAL BREAKER

AS AN EARLY ADOPTER OF NEW TECHnologies, I seriously looked into Vonage and what it had to offer. While Simson Garfinkel's article "Dial *N* for Net Phone" (*TR* March 2004) covered some good points, it left out one of the most important—which, for me, was the deal breaker. What Garfinkel doesn't mention is that every time Vonage customers dial out, they must use the full 11-digit numbers (*1* plus the area code) of the parties they are calling, even next-door neighbors. Likewise, everyone who calls your Vonage number must also dial the full 11-digit number. I don't need my local friends or doctor's office constantly receiving that annoying message telling them to dial my full number starting with the area code. They might think I moved out of state without telling them.

John A. Cantera
Essex Junction, VT

GARFINKEL FAILS TO RECOGNIZE AN important point with regard to Internet telephony. Whatever protocol is used to transmit voice or data, it still uses someone's physical network. These networks can't be run for free. If the Federal Communications Commission and authorities in other countries continue to refrain from applying fees for use of the Net for voice service, then there will be an incentive for service providers to move to that technology. The ultimate result of this shift, however, will be that there are no network facilities on which to deliver the service. To provide for the maintenance and expansion of networks, it is necessary to charge either the end user or the service provider for access to that network. The adage remains true: there's no such thing as a free lunch.

John Harris
Tulsa, OK

PONTOONS OF YORE

IN RESPONSE TO "BRIDGE OVER RISING Water" (*TR* March 2004): floating bridges are hardly new technology. Xerxes' army used a pontoon bridge circa 480 BCE to invade Greece, and armies have been using them to great success ever since. Today, U.S. Army combat engineers can assemble a floating bridge that can carry the weight of an M1 Abrams tank in less than a day.

Andrew Tabar
San Diego, CA

WHY CLOSE THE DOOR?

I WAS PLEASED TO READ "THE PATRIOT Act: A Visitor's Tale" (*TR* March 2004). Unfortunately, what happened to "Ahmed" is not rare. As an expert in the field of immigration law, I have seen huge backlogs and delays, and even unlawful refusals of visas. This not only hurts people, it damages American employers, universities, research, science, and technology, and the U.S. economy. Brilliant scientists and physicians are stuck abroad for months waiting for security clearance. U.S. Citizenship and Immigration Services has enough cases pending to count against this year's 65,000 H-1B visa cap so that technology and biotech companies, as well as other U.S. employers, can't hire professionals like "Ahmed" until October 2004. Amendments to increase the cap have been unsuccessful so far. The more people hear about these stories, the better chance we have to abolish bad practices.

Karen Weinstock
Atlanta, GA

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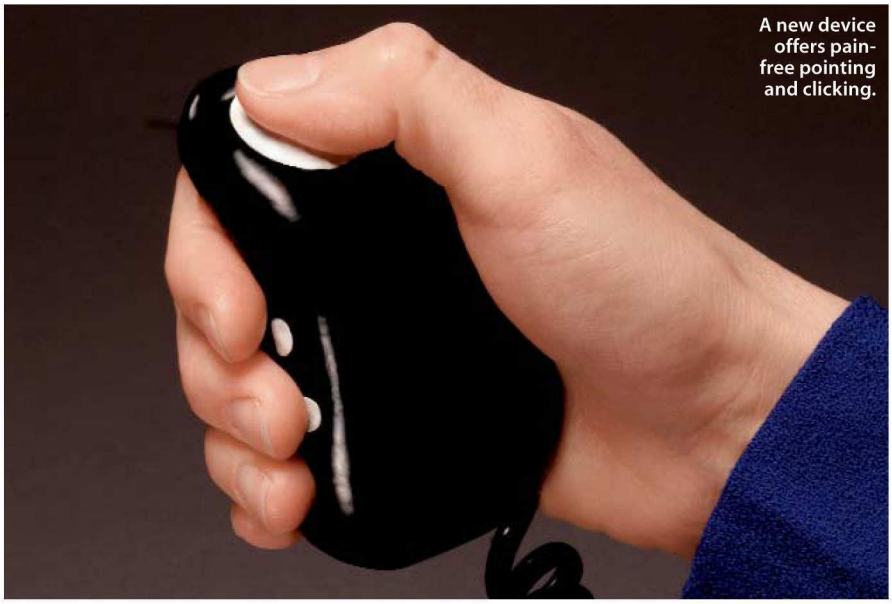
BONE BONDER

IMAGINE IF WEAK OR INJURED bones could be repaired simply by injecting a patient with a soft material that, once inside the body, would bond to existing bone at the molecular level, matching its hardness and strength. Researchers from Uppsala, Sweden-based Doxa have recently started human tests of just such a patching material. Today's artificial-bone materials, usually made from calcium phosphate or polymers, either have serious side effects or are not strong enough to replace bone in certain areas, such as the spine. Doxa's material, however, reacts to body fluids to form apatite, the body's own ceramic, to make artificial bones just as strong as the original. If the material proves to be as good as inventor Leif Hermansson, a materials scientist at Uppsala University, claims, it could bring relief to millions of patients. In the United States alone, an estimated 10 million people suffer from osteoporosis—one of the first disease targets for which Doxa hopes to get the material approved, perhaps within the year.

Repaired areas are whiter in this vertebra.

WI-FI MADE EASY

Researchers at the Palo Alto Research Center (PARC) in California have come up with software that lets users set up secure communications between the devices in a home Wi-Fi wireless network in less than a minute. A user who wishes to add a device, such as a laptop, to the network need only point it at an infrared port attached to the base station. Over the infrared channel, the devices swap digital addresses and short "fingerprints" of cryptographic keys. Then they switch to a Wi-Fi radio channel where they can use the fingerprints to identify each other and exchange full encryption keys, automating the process of making further communications indecipherable to eavesdroppers. Normally, the process is so tedious that many Wi-Fi users don't bother, leaving their networks open to hackers and piggybackers. The PARC researchers say they hope to license the software to hardware companies this year.



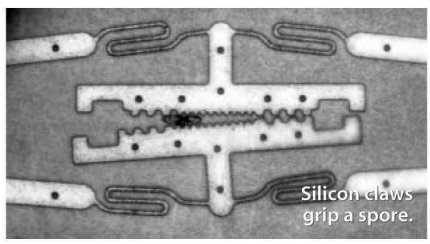
A new device offers pain-free pointing and clicking.

UNDER YOUR THUMB

LIKE SO MANY PEOPLE WHO USE COMPUTERS ALL DAY, ABIR QAMHIYAH AND her colleagues in Iowa State University's Mechanical Engineering Department found that the mouse-intensive software they used was giving them numb hands and painful wrists—the signs of carpal tunnel syndrome. But rather than submit to the traditional solutions—wrist splints, painkillers, or even surgery—Qamhiyah decided to develop a new kind of pointing device, one that would leave the wrists out of the equation. The result: a kind of joystick without a base, with a pressure plate at the thumb end that can be used to move an on-screen cursor in any direction. Says Qamhiyah, "We looked at how much force a thumb is capable of exerting, and we specified the sensitivity range to be on the very low end"—meaning the new pointer shouldn't cause its own ergonomic nightmares. Two buttons on the side take care of left-clicking and right-clicking. Iowa State is looking for corporate licensees to bring the device to market.

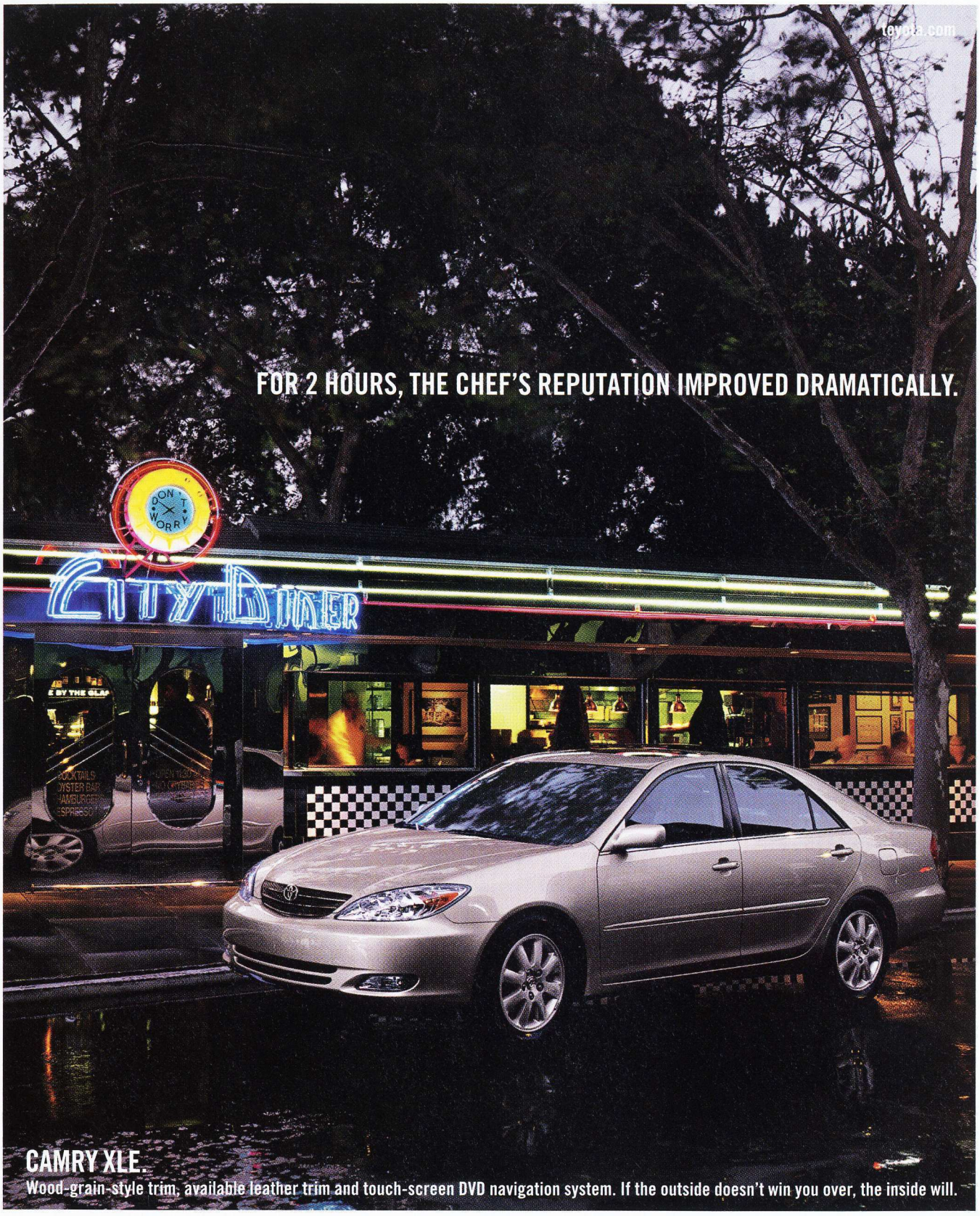
CELL SQUEEZER

SUPERMARKET SHOPPERS SQUEEZE fruit to see if it's ripe. The same sort of test could one day be applied to cells in a lab dish as a way of diagnosing disease. Ted Hubbard, a mechanical engineer at Dalhousie University in Halifax, Nova Scotia, has developed a pair of silicon claws small enough to squeeze individual cells just a few micrometers in diameter. Using spring-loaded joints controlled by an electrical current, the microgripper can measure the force needed to break the cells, an indicator of cellular health that could be used to test, say, blood cells for infection or cells from a biopsy to see if they are cancerous. Hubbard has shown that his device can grip dead, dry cells, and he is now developing a version able to grab live cells in liquid. He is part of a group of researchers that plans to develop, within seven years, a prototype micromachined diagnostic device incorporating the microgripper, for the lab or doctor's office.



Silicon claws grip a spore.

COURTESY OF THE DALHOUSIE UNIVERSITY MEMS LAB (SQUEEZER); COURTESY OF IOWA STATE UNIVERSITY (THUMB); COURTESY OF DOXA (BONE)

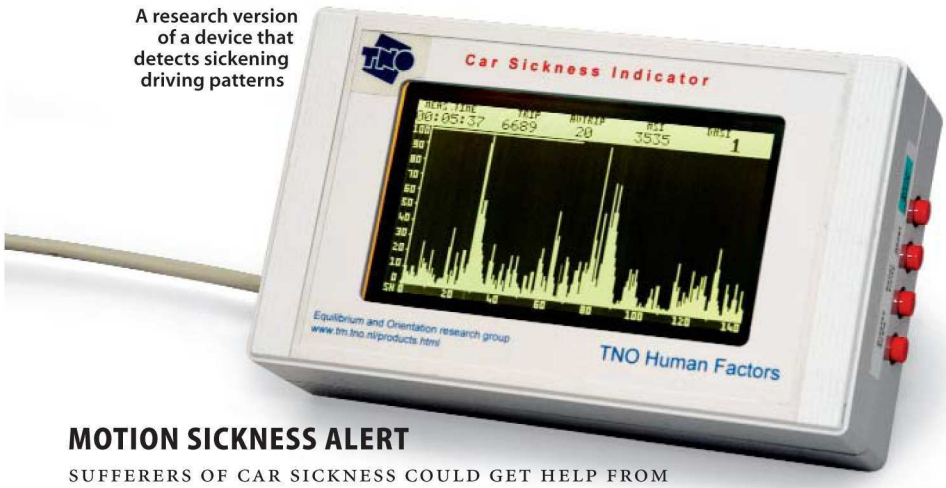


Vehicle shown with available equipment. ©2003 Toyota Motor Sales, U.S.A., Inc.

SQUEAL STOPPER

BRAKES—EVEN NEW ONES—ARE PLAGUED WITH THE PROBLEM OF SQUEAL, A MAJOR cause of consumer complaint and warranty repairs. The exact cause is unclear, but according to one theory, the rotor and pads vibrate from the friction of rubbing together, creating a high-pitched screech that squeal suppression tactics such as replacing the pads don't always cure. Ken Cunefare, a mechanical engineer at the Georgia Institute of Technology, says he has a better solution: a small cylinder housed inside each brake piston. The device holds several layers of a piezoceramic material that stretches when a voltage is applied across it. Every time the driver hits the brakes, a varying voltage is applied to the device, and the material grows or shrinks a few hundredths of a millimeter—changing the force with which it presses against the steel plate on the back of the brake pad. The pulsing pressure causes the brake to vibrate at a higher, inaudible frequency. Cunefare has done lab tests and is looking for a corporate partner to help him build a second-generation prototype that he could road-test on cars.

This gizmo keeps brakes quiet.



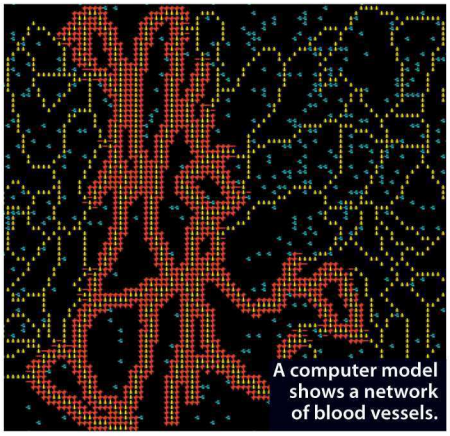
A research version of a device that detects sickening driving patterns

MOTION SICKNESS ALERT

SUFFERERS OF CAR SICKNESS COULD GET HELP FROM a device that plugs into a car's cigarette lighter and alerts the driver that passengers will be ill unless his or her driving improves. "Drivers rarely feel sick, so they blame it on their passengers—who are often children—because they are more susceptible," says inventor Jelte Bos of TNO, a Dutch organization for applied scientific research, in Soesterberg, the Netherlands. But, Bos says, "It's largely due to driving style." His prototype car sickness indicator contains three accelerometers to sense motion along three axes and a microchip to calculate how nauseating the car's motions are. An LCD screen on the prototype shows the percentage of people who'd feel ill if exposed to a given driving performance, but this would be replaced on production versions by colored LEDs like the lights of traffic signals. A red light, for example, could indicate that a passenger is likely to soon become ill. Bos is showing the patented invention to auto engineers and hopes it will become standard on car dashboards. Sensitive children—and parents who clean up after them—would be grateful.

PRINTING TISSUES

Tissue engineers have tried a number of schemes for building replacement organs out of patients' own cells, but biophysicist Gabor Forgacs at the University of Missouri-Columbia has a new twist: let the cells assemble themselves. Forgacs and his team start with a printing device built by Sciperio, an R&D firm in Stillwater, OK, loaded with what he calls "bioink." The bioink consists of spherical aggregates of many thousands of cells. The printer deposits the aggregates onto successive layers of biodegradable gel; by manipulating the composition of the gel, Forgacs can coax the aggregates to grow together to form complex structures while the gel degrades. Forgacs has already built three-dimensional blood-vessel-like modules and thinks a usable blood vessel will be ready in the near future. Another application Forgacs envisions is in cancer treatment. Doctors could take tumor cells from a patient, build an artificial replica of the tumor outside of his or her body, and see which drugs worked best on the replica before barraging the patient with different treatments.

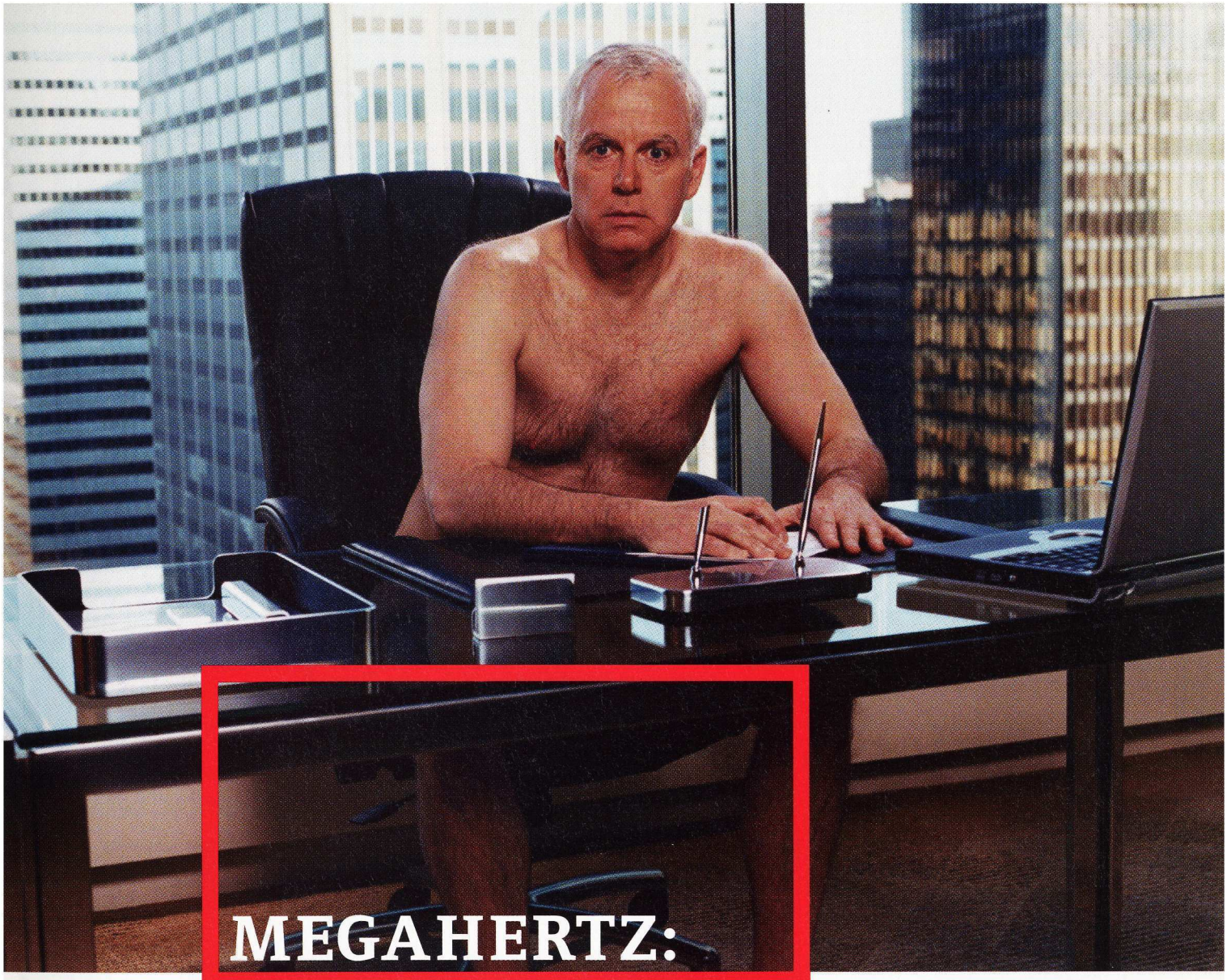


A computer model shows a network of blood vessels.

OPTIMIZING RECOVERY

A NEW COMPUTER MODEL COULD SOON HELP RESEARCHERS DETERMINE HOW best to treat patients during the early stages of heart disease and how to promote healing after surgery or stroke. Using data from previously published research, Thomas Skalak and his colleagues devised more than 50 rules that, together, can predict how cells involved in the development of new blood vessels will respond to stimuli such as growth proteins or drugs. Skalak, the chair of the biomedical engineering department at the University of Virginia, hopes the model will help researchers figure out which existing or potential drugs—and what specific sequence of drugs—will stimulate new vessels to form in tissue damaged by injury or disease. "I consider it a breakthrough," says Steve Burbeck, a senior researcher at IBM Life Sciences. "This model can highlight therapeutic regimens that you would never find by trial and error." A patent for the model is pending, and Skalak is seeking a pharmaceutical company or startup with which to partner.

COURTESY OF THE THOMAS SKALAK LABORATORY TEAM (RECOVERY); COURTESY OF TNO HUMAN FACTORS (MOTION SICKNESS); GARY MEEK (SQUEAL)



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Florida Life Science Events to Highlight Credentials

In recent years, Florida has become a rising star as a location for life science businesses -- ranking 11th nationally in the number of biotech firms and 2nd in the number of FDA-registered medical device establishments. With the November 2003 news that The Scripps Research Institute will build a major R&D facility in South Florida (the only Scripps facilility outside California), the future looks brighter than ever for life science development in the state.

Life science is the focus of several up-coming events that demonstrate Florida's strength in: biotechnology, drug discovery and manufacturing, biomedical research, health care, and medical device manufacturing. Here is summary of up-coming activities:

BIO 2004

June 6-9, 2004

Look for the Florida Pavilion at this year's BIO2004 conference at San Francisco's Moscone Center. Located at booth #5333, the Florida Pavilion will include representatives from: Nabi Biopharmaceuticals, The Broward Alliance, Enterprise Florida, Florida High Tech Corridor, Florida's Research Universities, Jacksonville - Northeast Florida, Miami-Dade Beacon Council, Palm Beach County, Florida, and Southwest Florida.

M&M EAST

June 15-17, 2004

Florida's medical device manufacturing sector takes center stage at MD&M East at New York City's Jacob K. Javits Convention Center. Look for Florida representatives at booth #2619.

webex

May 25, 2004

The Florida Life Sciences Webinar* is a live, interactive presentation featuring representatives from The Scripps Research Institute, a Florida research university, a prominent life science company and a venture capital firm. Advance registration (free) is available on eflorida.com/bio. *Attendance is limited.

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Much Ado about Invention

SAMUEL F. B. MORSE DIDN'T INVENT THE TELEgraph. Alexander Graham Bell didn't invent the telephone. Thomas Edison invented neither the light bulb nor the movie camera. Guglielmo Marconi most assuredly didn't invent radio. Neither Philo Farnsworth nor Vladimir Zworykin invented television. The integrated circuit's provenance remains in simmering dispute between Jack Kilby fans and Robert Noyce supporters. As for the Internet and its ubiquitous browser, let's just say that—as with these other technological "breakthroughs"—"publicity," "priority," and "patent" are often mutually exclusive.

When it comes to invention, Henry Ford—who, of course, invented neither the automobile nor the mass-production line—was right: history is indeed bunk. The wrenched context and sheer dishonesty of most sagas of "heroic" inventors and their profitable progeny brings to mind science historian Otto Neugebauer's astutely cynical observation that "The common belief that we gain 'historical perspective' with increasing distance seems to me to utterly misrepresent the actual situation. What we gain is merely confidence in generalization that we would never dare to make if we had access to the real wealth of contemporary evidence."

Amen. If you want to learn about the importance of "invention" over the past 300 years, talk to the lawyers. If you want to hear about the importance of "innovation," however, talk to anyone else. The history of invention is the story of litigation, not innovation. Don't confuse them.

That's why I can't help but sigh when I read about a coming renaissance in invention or a technology-driven resurgence of talented amateur/multidisciplinary professional inventors. The role of invention in innovation is vastly overblown. Do we think it's a mere accident of history that so many scientific discoveries or technical inventions emerge simultaneously from several different laboratories? Is anyone shocked anymore when the so-called original inventor wins at the patent office but loses in the marketplace?

There is no correlation between a successful act of invention and a successful marketplace innovation. None.

The simple truth is that the economics of invention are profoundly different from the economics of innovation. Being "first to file" has nothing to do with being first to market. Being first to market has nothing to do with being first to profitability. Being first to profitability—and this is key!—has virtually nothing to do with how quickly, deeply, and ubiquitously an innovation spreads. In other words, there is no meaningful correlation—let alone causality—between a "successful" act of invention and a "successful" marketplace innovation. None.

Why should this surprise us? The marketplace triumphs of "winners" like Edison and Marconi were less a function of inspired inventorship than of ruthless business practice. We shouldn't confuse the creation of an idea with its commercialization, any more than we should confuse an airplane with an airline or a telephone with a network.

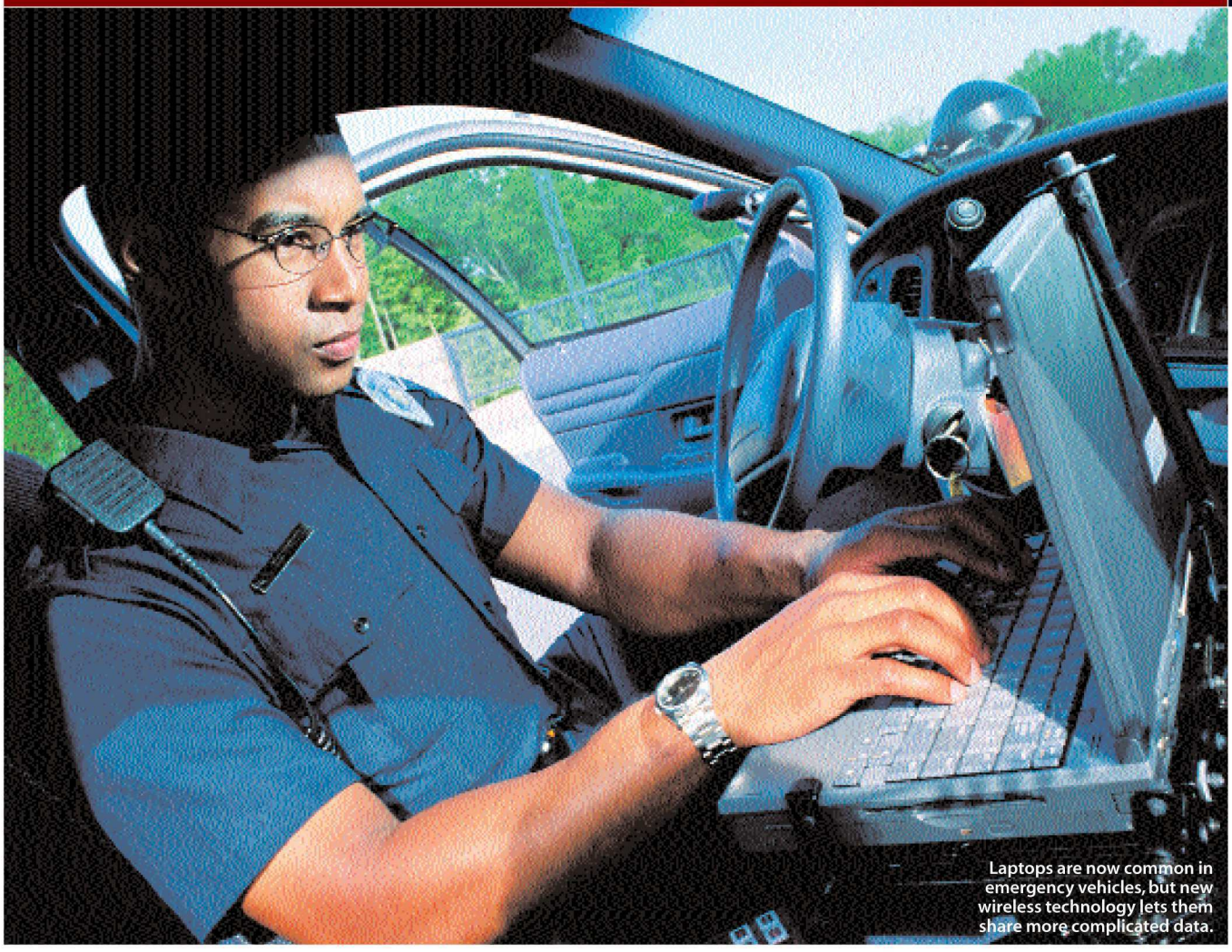
Occasionally, markets understand this. IBM was a patent powerhouse throughout the 1980s. Alas, Big Blue's gigantic portfolio of government-certified "intellectual-property" wealth failed to translate into superior investment returns for what had once been the world's most valuable IT company. Patent productivity is a lousy measure for innovation that matters.

Look no further than the Internet bubble to see the total market disjunction between invention and innovation. The Internet suffered no shortage of truly inventive ideas. Unfortunately, there was a shortage of customers and clients who would actually pay a premium for them. In those halcyon days of 1995 to 2000, dot coms literally gave away the fruits of their inventions in hopes of first capturing business and then, finally, in hopes of staying alive. Even when the new inventions were effectively "free," most of them failed.

The world is not suffering from a lack of inventiveness. Indeed, Econ 101 teaches that when the rate of supply dramatically accelerates past the rate of demand, supply becomes *less* valuable; you have a glut. If the U.S. government increased the number of patents it grants by a factor of ten, do we think inventions would—on average—become more valuable? Almost certainly not. Similarly, the romantic belief that dramatically increasing the number of quality inventors will dramatically increase the number of brilliant innovations is to misunderstand both the act of invention and the process of innovation. The real bottleneck isn't invention; it's the inability to cost-effectively translate breakthrough inventions into marketable products.

Without belittling the genius of the inventive spirit, I would suggest taking a more Neugebauerian perspective: the technical excellence of an invention matters far less than the economic willingness of the customer or client to explore it. A *customer's* readiness to innovate is what makes invention possible. That's why *Technology Review* is MIT's Magazine of Innovation—not Invention. Good call.

A researcher and consultant on innovation economics, Michael Schrage is the author of *Serious Play* (Harvard Business School Press, 2000).



Laptops are now common in emergency vehicles, but new wireless technology lets them share more complicated data.

COURTESY OF NEXGEN CITY INC.

Communicating in Crisis

New technologies could help avoid breakdowns like those of September 11. **BY CORIE LOK**

Among the tragedies of the September 11, 2001, terrorist attacks in New York City were those caused by an almost complete communications meltdown among emergency workers at the scene. While police got the order to evacuate from the World Trade Center's burning north tower, for instance, firefighters didn't—and many of them were still inside the tower when it finally collapsed. And that was only one of a number of communication failures that directly or indirectly cost lives. The inability to track personnel, to get pictures from TV news reports or helicopters showing the condition of the towers, and even incompatible radios that couldn't talk to each other all contributed to the disaster.

Help in improving communications among emergency workers, however, is on the way. Wireless networking technologies being tested and deployed in U.S. communities could solve at least part of the problem. The new networks are providing police and firefighters a way to pass vital data such as video, maps, and photos among themselves quickly and easily. Voice communications may take longer to modernize and integrate, but observers point to progress in an area called "software radio" that will let emergency workers from different agencies talk with each other more easily.

Wireless laptops that display information such as drivers' records have been a common feature in police cars for

at least a decade. But they have typically been connected via cellular networks that deliver data at dial-up-connection speeds or even slower, meaning that they are generally limited to receiving text. But now, faster data networks for police cars, fire trucks, and ambulances are giving officials access to more kinds of data and allowing them to share it with each other. Starting in May, for instance, fire, police, and ambulance workers in Garland, TX, will be able to use their existing laptops to send and receive mug shots, fingerprints, live video, medical data, and even floor plans at DSL-like speeds—while racing along at highway speeds.

High-speed "mesh networks" will let officials exchange mug shots, fingerprints, live video, medical data, and even floor plans while racing to emergency scenes.

Garland's system, developed by partners NexGen City of Richardson, TX, and MeshNetworks of Maitland, FL, uses a technology called mesh networking, in which the laptops instantly become nodes in a network simply by being on and within range of each other. Each laptop routes data to others nearby, so that data crosses the network by hopping along the most efficient path from one laptop to the next. By avoiding the tower-based, hub-and-spoke configuration typical in cellular networks, mesh networks can work around dead spots created by interference from buildings.

They are also self-healing, meaning they simply reconfigure themselves if any node is lost, says Rick Rotondo, MeshNetworks' vice president of technical marketing. Consequently, no single node is indispensable, as a central tower is in a cell network. Mesh networks can also route data around bottlenecks to ensure fast transmission, and their range of coverage can easily be extended by attaching additional routers to traffic lights and lamp posts. The Garland system offers coverage across more than 150 square kilometers.

"To the guy on the street, [high-speed data in vehicles] is going to make a huge difference," says Joe Hanna, a consultant in Dallas, TX, and a past president of the Association of Public Safety Communications Officials. In addition to Garland, MeshNetworks is installing its system in Medford, OR, and has several trials and commercial deployments under way with other cities in the United States, Europe, and Asia.

While sharing data among emergency responders is relatively simple, sharing voice communications is actually far more difficult, since different radios are hardwired to transmit and receive at specific frequencies using different communications protocols. One solution could be software radio, in which radios store programs that automatically switch frequencies and communications protocols as needed to communicate with other devices. Cambridge, MA, startup Vanu, for example, is demonstrating a Compaq iPAQ handheld computer equipped with radio software that police or fire officials can use to communicate directly with different public-safety radios on any frequency between 100 and 500 megahertz. Meanwhile, Thales Communications in Clarksburg, MD, will target state and local agencies with a smaller, lighter version of a software radio it now sells to the military. "I think software radio will be the ultimate solution to the interoperability problem," says John Powell, a public-safety technology consultant to the U.S. Departments of Homeland Security and Justice.

It's unclear how readily software radio or mesh networking will be adopted by fire and police departments across the country, which often struggle simply to keep their existing equipment from becoming obsolete. And beyond the technical and financial challenges, there is still the hurdle of overcoming traditions. Different agencies have historically resisted cooperating with each other when buying radios, although that is beginning to change, says Craig Jorgensen, who is working with the Association of Public Safety Communications Officials and other groups to develop a standard for radios for emergency workers. Working together, Powell says, public agencies may help push to market technologies that could prevent a tragic communications crash like the one that occurred on September 11. But in the end, finding a solution will depend on how well the different officials listen to each other.

CONNECTING FIRST RESPONDERS

COMPANY	TECHNOLOGY
MeshNetworks (Maitland, FL)	Hardware for wireless broadband mesh networks
NexGen City (Richardson, TX)	Hardware for wireless broadband mesh networks
PacketHop (Belmont, CA)	Software-based mobile mesh networks for interoperable data communications
Raytheon JPS Communications (Raleigh, NC)	Patching devices to allow different radios and telephones to talk to each other
Thales Communications (Clarksburg, MD)	Software radio
Tropos Networks (San Mateo, CA)	Mesh networks using Wi-Fi wireless broadband
Vanu (Cambridge, MA)	Software radio

GENETIC ENGINEERING

Biotech Bugs Take Wing

A pink bollworm larva ravages a cotton plant.

EACH YEAR, THE LARVAE OF THE pink bollworm cause more than $7 million in damage to the U.S. cotton crop. Now, in the first open-field release of a genetically modified insect, entomologists hope to show that genetically engineered versions of this small moth could help control or even eliminate this major pest. Not only could the project protect the nation's approximately five million hectares of cotton crops, but it could clear the way for the testing of other genetically modified insects as a more effective and environmentally benign alternative to pesticides.

The U.S. Department of Agriculture has approved plans by its scientists to conduct a full field release of the biotech bollworm in the summer of 2005, following several years of tests in enclosed fields. In this trial, the insects will contain only an extra gene that makes them fluoresce under ultraviolet light, allowing researchers to distinguish the laboratory-bred bugs from wild bollworms. "We're trying to see how the transgenic animals behave in the field," says University of California, Riverside, entomologist Thomas A. Miller, who led the effort to modify the insects.

In the long run, though, the researchers hope to release moths carrying genes that will kill offspring in the embryonic stage after the altered moths interbreed with wild bollworms. Luke Alphey, a University of Oxford entomologist, developed the requisite genetic technology and has formed a startup, Oxitec, to commercialize it.

Not surprisingly, the biotech bugs have raised red flags among environmentalists who worry about unforeseen consequences of releasing engineered insects. "We're not terribly good at predicting what happens if you introduce something new into an environment, on a broader ecosystem level," says Michael Fernandez, director of science at the Pew Initiative on Food and Biotechnology, which published a report last winter on concerns about genetically modified insects. One of the biggest fears: that the new genes might escape into other species, perhaps accidentally eradicating beneficial insects.

The scientists performing the pink bollworm work say that because of the methods used, and because insects tend not to breed across species lines, such an incident is extremely unlikely. "It is an issue, and one has to think about it carefully," says Alphey. "But there are very low risks." A test release of moths carrying the embryo-killing genes will not be planned until the researchers find a gene package that works well in moths. Meanwhile, researchers are busy modifying several other insects to control other crop and livestock pests. **Erika Jonietz**

GENES FOR PEST CONTROL

PEST/TARGET	ORGANIZATION/LOCATION	STRATEGY/STATUS
Codling moth/ apple orchards	U.S. Department of Agriculture Agricultural Research Service, Wapato, WA	Embryo-killing genes; in early lab tests
Red flour beetle/ grain	USDA-ARS, Manhattan, KS	Studies to find genetic control methods
Screw worm fly/ livestock	USDA-ARS, Lincoln, NE	Genetic method to increase proportion of male flies bred for traditional sterile-insect release program; in lab development
Tobacco budworm/ cotton, tobacco, tomatoes	University of California, Riverside	Studies to find genetic control methods

COMMERCE

ATMs Go beyond Cash

What sells movie tickets, cashes checks, lets you add minutes to your cell-phone account, and spits out a stack of crisp twenties? It's your neighborhood ATM—now equipped with a new computer that's more like a multimedia PC than the familiar dumb bank terminal.

Since the 1980s, most ATMs have been built around simple, slow computers with low-bandwidth telephone connections back to the bank. But a new generation of ATMs from companies such as Diebold of North Canton, OH, and Triton of Long Beach, MS, have fast, updated processors, a Microsoft Windows operating system, and quicker network connections based on the same protocols used on the Internet. That means they can handle complicated software for cashing checks, making money transfers, or displaying graphics as varied as any found on the Web.

A new Triton ATM prints coupons.

One of the main advantages of the new ATMs is that their interfaces can be customized for each user, says Steve Grzymkowski, a product-marketing manager with Diebold. Once a customer has identified himself or herself to a machine using an ATM card, "the screen would appear like a personalized website with options showing your preferred transactions, or even have a ticker for your stocks or advertisements of your favorite accessories," Grzymkowski says. And because they run Windows, it's easy for software developers to write new programs for them. For example, NCR, a bank machine manufacturer headquartered in Dayton, OH, offers software that lets ATM users buy movie tickets or prepaid long-distance tele-

JACK KELLY CLARK, COURTESY OF UC STATEWIDE IPM PROGRAM (BUGS); COURTESY OF TRITON (ATM)

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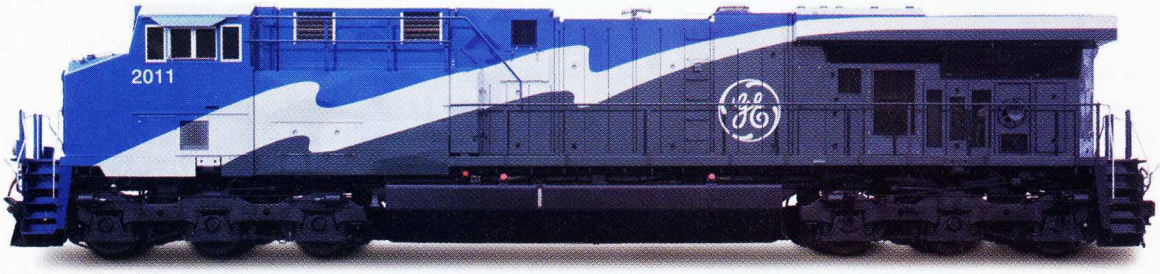

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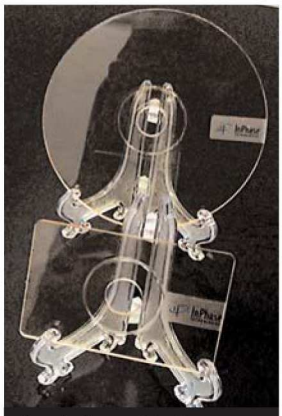
HARDWARE

Holostorage for the Desktop

You could store a whole lot of stuff on a one-terabyte computer disc—say, a million novels, 250,000 MP3 song files, or hundreds of full-length movies. A Lucent Technologies spinoff is hoping to bring you that kind of capacity using a long-talked-about technology: holographic storage, in which a laser records data in three dimensions on a polymer medium. The technology can store up to 300 times as much data as traditional optical drives of the same physical size, and the startup, Longmont, CO-based InPhase Technologies, says it will start selling the holographic drives next year.



Clear holographic discs may put DVDs out to pasture.

InPhase's initial product, with discs capable of storing 200 gigabytes and reading and writing data four times as fast as today's DVDs—will be relatively expensive and marketed to companies and government agencies. Because they can read large chunks of data at high rates, the drives could be ideal for uses such as image searching and comparison. InPhase's first target market will be organizations with large image-archiving needs, such as the mapmaking agency that supports the U.S. defense and intelligence communities.

But the company hopes holographic storage will eventually be available to consumers, and along with rival holographic-media startup Aprilis, a Polaroid spinoff in Maynard, MA, it's licensing the technology to companies such as Sony and Sanyo, which should have products on the market within four years. In fact, says analyst Wolfgang Schlichting, a research manager at IDC, an information technology consultancy in Framingham, MA, it's the work done by electronics manufacturers to create accurate and cheap lasers and sensors for CD players, digital cameras, and DVD drives that is making holographic disc drives affordable.

Schlichting thinks the technology is a promising successor to today's magnetic and optical storage products but points out one big remaining limitation: the holographic medium—a photosensitive polymer that records and stores the data—isn't yet rewritable. In the meantime, InPhase expects to market its own non-rewritable, 200-gigabyte holographic drives late next year. But a rewritable drive is just a couple of years away, the company says. **Patric Hadenius**

MEDICINE

Testing New TB Vaccines

Tuberculosis is the world's deadliest infectious disease, sickening eight million people and killing two million every year. A century-old vaccine prevents childhood forms of the disease. But there's a desperate need for a vaccine that's effective against the adult form of the disease, which is highly contagious and is growing resistant to drug treatment. Renewing hope on this front, two human trials of vaccines that could be protective against the adult form of the disease began in the United States earlier this year.

In one of the trials, Corixa, a biotech firm in Seattle, WA, and GlaxoSmithKline Biologicals of Rixensart, Belgium, are testing the safety of their vaccine on 20 healthy volunteers. Whereas the childhood vaccine consists of live bacteria closely related to the TB-causing germ, the new one is made of two proteins isolated from the TB bacterium using genetic-engineering techniques. Corixa researchers picked these proteins in part by screening the blood of adults who successfully fought off the infection. Because their immune cells—presumably adept at killing tuberculosis germs—most readily recognized these two proteins, it's thought that the proteins will stimulate a stronger and more effective immune response among adults. And because it's not live, the vaccine could be easier to manufacture and store in large quantities, says Christine Sizemore, tuberculosis program officer for the National Institute of Allergy and Infectious Diseases in Bethesda, MD.

A second U.S. clinical trial, led by Marcus Horwitz, a professor of medicine and microbiology at the University of California, Los Angeles, is using a live vaccine in which the same organism used in the childhood vaccine has been engineered to produce extra immune-stimulating proteins. Even if these trials go well, it could be another decade before a new tuberculosis vaccine gets regulatory approval, says Sizemore. But after years of lackluster progress against the killer disease, even getting this far is, in her words, "a true quantum leap." Corie Lok

OTHERS BATTLING TB

RESEARCHER	TECHNOLOGY
Stewart Cole Pasteur Institute, Paris, France	Same TB bacterium relative used in existing vaccine, but engineered to carry several genes from the TB bacterium; in animal testing
Helen McShane University of Oxford, Oxford, England	Genetically engineered virus carries a protein from the TB bacterium; in early human trials in the U.K. and the Gambia
Fordham von Reyn Dartmouth Medical School, Hanover, NH	Heat-killed bacteria related to the tuberculosis bacterium; in human trials with HIV-positive subjects in Tanzania

COURTESY OF INPHASE TECHNOLOGIES (HOLOSTORAGE)

2:01AM CHECK INTO HOTEL 2:11AM CHECK INTO INTERNET 2:26AM WORM ENTERS ROOM 536 2:28AM WORM EVACUATED BY NETWORK 2:32AM ORDER GRILLED CHEESE AND FRIES 2:35AM DOZE OFF

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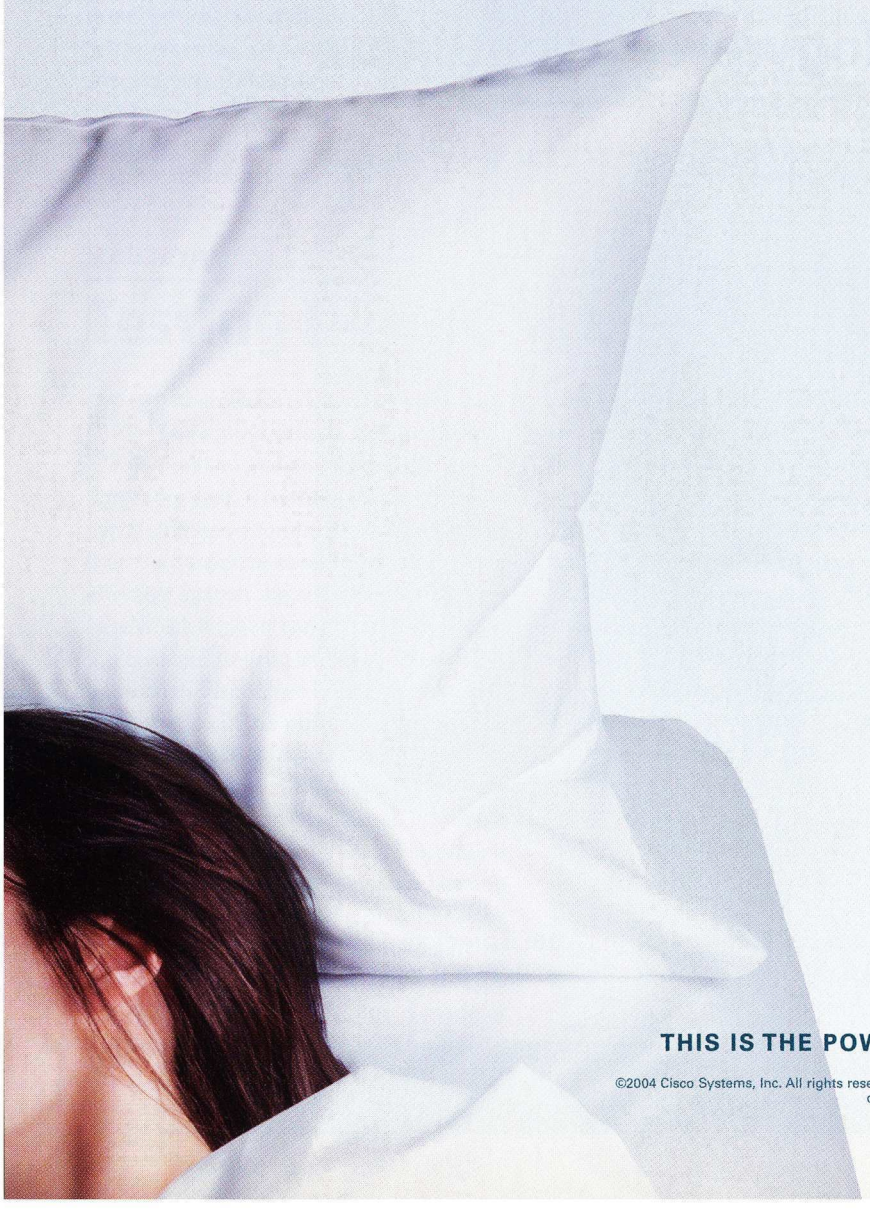

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LETTER FROM JAPAN

Humanoids for the Home

EVERYONE IN JAPAN KNOWS the exact date on which the Age of Robots began: April 7, 2003, Astro Boy's birthday.

Astro Boy was the cartoon robot created by legendary Japanese animator Osamu Tezuka in 1951. Featured in a hit TV series in Japan and the United States in the 1960s, Astro Boy had rockets in his legs, searchlights in his eyes, and machine guns in his shorts. He inspired a generation of roboticists. Tezuka set his birthday in 2003, because he was sure that by then autonomous humanoid machines would be everywhere.

Tezuka wasn't that far off—in Japan, anyway. The most visible example is a herd of toys ("entertainment robots," in the jargon) jamming upscale-Tokyo-store shelves, among them Sony's well-known Aibo robot dog, Sega Toys' Poo-chi (a big-headed, blue-eared pooch), and scheduled for spring, a robot cat from toymaker Bandai.

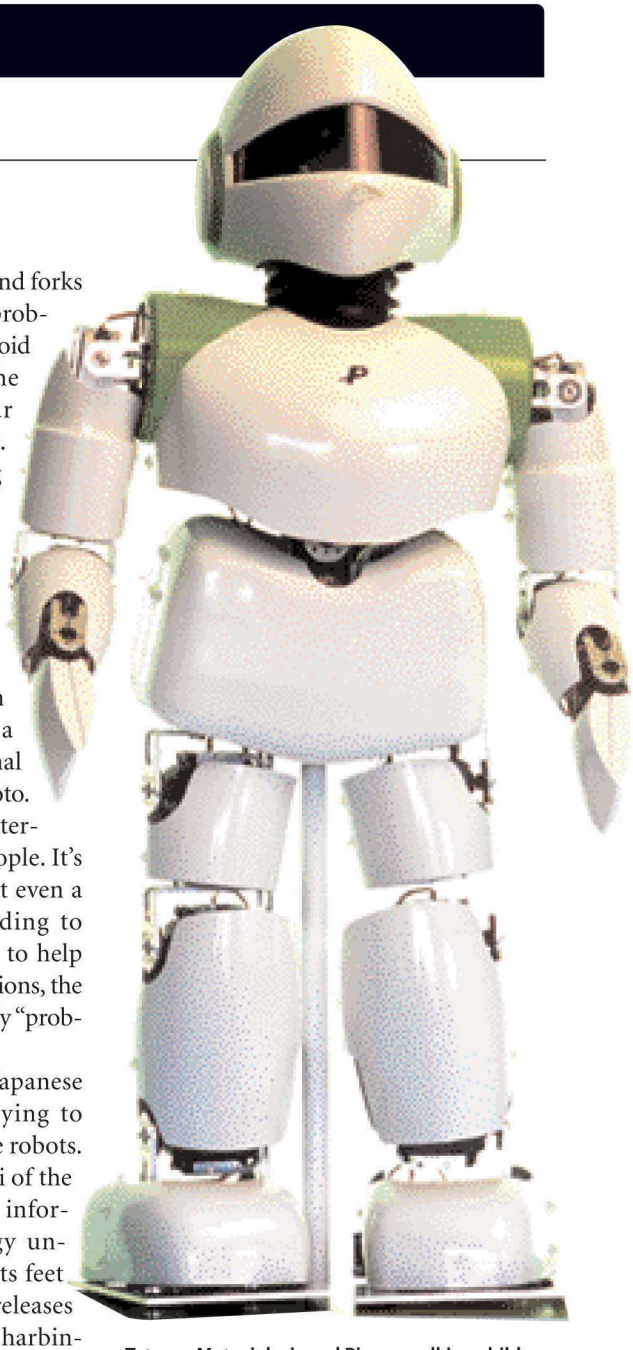
The toys are just the beginning. Japan's Ministry of Economy, Trade, and Industry plans for robots to become one of the country's key industries, as important as automobiles and consumer electronics. The government is disbursing $28 million this year for robot development; industrial powerhouses like Fujitsu, Honda, Toyota, and Kawada also have robot projects. By 2010, the ministry hopes, full-fledged, humanoid robots will be common sights in middle-class homes.

Some scientists outside Japan have disparaged this goal, because robots, strong and heavy, will pose a danger to their owners. "What if it thinks Grandma's head is a vase and tries to put it away?" asks Mark W. Tilden, a well-known U.S. researcher who has built robots for NASA and is now working on the design of a walking toy robot called Robosapien. Building machines to perform even simple tasks like dish-washing is a formidable challenge: they will have to recognize the difference between a plate and a Frisbee, manipulate glasses and crockery without breaking them, and stick knives and forks in the appropriate drawer. The problems are compounded for humanoid robots. Simply reproducing the bipedal walk has been a near intractable engineering challenge. "And after all that, you're building a half-million-dollar machine to wash the dishes," Tilden says.

Roboticists in Japan argue that the upside of humanoid robots far outweighs the downside. "Everything in the environment is already scaled for human beings," said Gordon Cheng, a roboticist at ATR Computational Neuroscience Laboratories in Kyoto. "People already know how to interact with things that look like people. It's a natural, intuitive interface that even a child can understand." According to Cheng, who is developing ways to help robots better interpret human actions, the safety and cost obstacles are simply "problems that need to be solved."

To that end, researchers in Japanese industry and academia are trying to develop nimbler, more adaptable robots. Last September, Yasuo Kuniyoshi of the University of Tokyo school of information science and technology unveiled a robot that can leap to its feet from a supine position. Press releases touted the accomplishment as a harbinger of tomorrow, when robot maids, nurses, and babysitters will tiptoe deftly about the home.

Help in negotiating the complex environment of a modern home, enthusiasts argue, will come from a network of tiny radio frequency identification chips. At the National Institute of Advanced Industrial Science and Technology in Tsukuba, scientists are training robots to sort and wash dishes by combining visual data with RFID input. If a robot sees something round and platelike, it scans the object. The plate's RFID chip reports, in essence, I'm a plate! I get washed and put in the corner cupboard, second shelf!



PETER MENZEL

Tatsuya Matsui designed Pino, a walking child-sized robot, to be cute and nonthreatening.

"We must make this work," says Tatsuya Matsui, a robot designer for the Kitano Symbiotic Systems Project, a government-funded effort to combine ideas from biology and computation. Japan, he points out, has both a very low birthrate and a very high average life span. Simple arithmetic suggests that the nation's relatively small cohort of young and middle-aged people will have trouble taking care of its huge population of senior citizens. "I am making the technology that will help me in my old age," Matsui says. "It's like putting retirement money into the bank." **Charles C. Mann**

Going with Plan B

"I BET ON JOCKEYS, NOT HORSES," NICHOLAS Negroponte, founder and chairman of the MIT Media Laboratory and an active angel investor, once told me. He was describing his strategy of placing more trust in the people who run a company than in its products and business plan, a strategy that reflects the common reality that a startup's initial plan often fails, for any number of reasons. The product may work well but not attract a single sale, or as is often the case in high tech, the product development may not go anywhere near as well as was hoped. A founder's ability to face down failure and rebound is a critical consideration for any investor, and virtually every successful entrepreneur has a near-death tale or two to tell. (I have several.) Conjuring up a winning Plan B when the fan is blowing brown requires a certain ineffable combination of decisiveness, perseverance, unconventionality, and plain old-fashioned luck.

Cynthia Bamdad, founder and CEO of Waltham, MA-based Minerva Biotechnologies, is still on her first startup, so she has yet to chalk up a major entrepreneurial victory, but her life is full of the lemons-to-lemonade stories that investors love to hear. At first glance, there is little remarkable about a 51-year-old scientist with a successful biochip invention behind her setting up her own startup laboratory. What is unusual is that 15 years ago she was an artist and stay-at-home mother with five school-age children, no higher-education degrees, and no scientific background whatsoever.

Bamdad explains: "I went through a sudden and traumatic divorce which left me with no child support or alimony and literally nothing in my name besides my Ferrari." Figuring that she was effectively unemployable, Bamdad sold the Ferrari and invested the proceeds in her own skills, enrolling at Northeastern University as a freshman and completing a degree in physics in three years. Her professors at Northeastern recommended her to Harvard University, and she dashed through her biophysics PhD there in five years, creating and patenting some of the seminal work in biochip technology. All while raising five children on her own. "I used to cook dinner at five in the morning so everyone could eat when we all got home," recalls Bamdad, "but it all wasn't as hard as you might imagine."

SCORECARD: MINERVA BIOTECHNOLOGIES

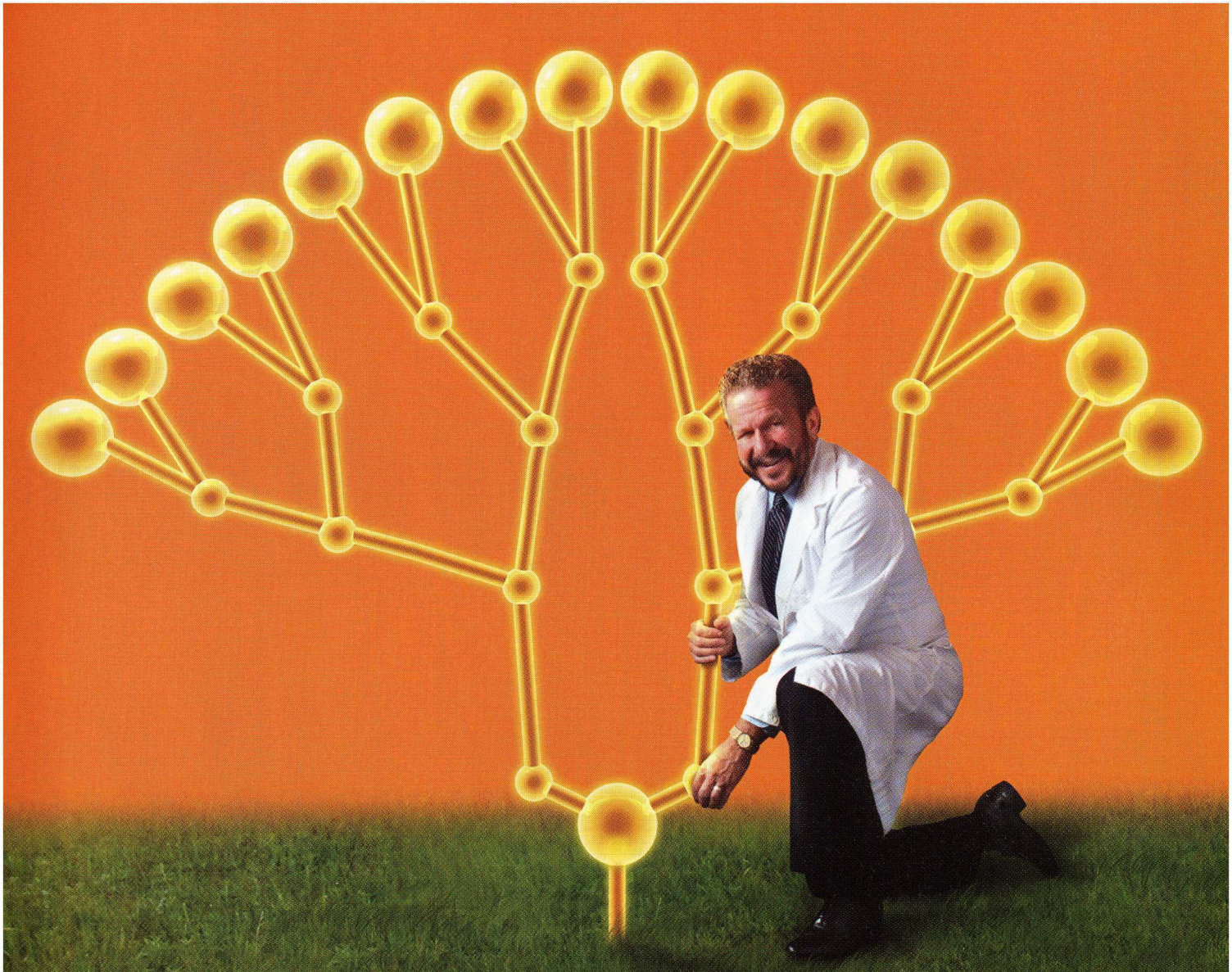
ELEVATOR PITCH	Hyperefficient nanotech biosensor
FUTURE VISION	Minerva's biosensors will find cancer cures and Alzheimer's therapies and help map the human proteome
CEO'S INSOMNIA	Failing to prove the commercial value of the technology to the biotech Goliaths
LEG UP	Groundbreaking research backed by aggressive patenting

Bamdad made the leap from academia into the entrepreneurial world when Clinical Micro Sensors of Pasadena, CA, licensed the biochip technology that she had patented at Harvard and hired her as chief scientific officer. In record time, she transformed her academic work into a commercially viable biosensor that tests for the presence of specific DNA sequences and communicates the results directly to computers for analysis—invaluable for diagnosing disease and providing early warning of biological-weapons attacks. Less than two years after her arrival, the company—and her inventions—were acquired by Motorola for $280 million. As a relative latecomer to Clinical Micro Sensors, Bamdad received a payout that, while significant, was nothing near the lion's share reaped by the founders and venture capitalists.

Like many first-time entrepreneurs, Bamdad was spurred to mount her own steed by watching someone else get extremely rich off of her work. Minerva Biotechnologies broke out of the gates on the heels of the Motorola acquisition, driven solely by Bamdad's conviction that she could develop commercially valuable intellectual property. One of the problems with biochips like the one she had already developed is that they work very slowly. They rely on random motion to jiggle the targets—proteins or strands of DNA, for example—into position until they bind to probes attached to the chip's surface. Bamdad and her Minerva researchers reasoned that if the probes were free to roam through the test solution in three dimensions, the binding would be orders of magnitude faster. A test that might have taken days to complete could be done in a matter of minutes.

The problem with free-roaming probes is detecting when one has successfully bound to its target. Bamdad solved that problem by attaching the probes to extremely tiny spheres of pure gold called gold nanoparticles, a feat that required her to also solve some tricky surface-chemistry problems. When the probes bind to their targets, the gold particles clump more closely together, causing the color of the solution to shift visibly from pink to blue. And by enabling the probes to interact with potential targets in three dimensions, Minerva lopped several zeroes off typical testing times.

Testing times matter greatly to pharmaceutical companies who seek to automate the screening of potential new drugs. But even more valuable to these companies is Minerva's ability to attach several different probes to each nanoparticle—enabling the detection of pairs of molecules joined together. This ability is critical in drug development, where a key factor is identifying whether or not a candidate drug hits its desired target. Bamdad has also used her nanoparticle techniques in attempting to understand certain disease



TREES INSPIRED DR. TOMALIA'S NANOTECHNOLOGY DELIVERY SYSTEMS.

HE PLANTED HIS COMPANY IN MICHIGAN.

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mechanisms, and she believes that she has developed a unique method of early detection for many types of common cancers, including breast cancer.

In addition to applications in drug screening and disease diagnosis, Minerva is going after the hot field of proteomics—the effort to study all 500,000 or so proteins encoded in the human genome. Identifying these proteins and understanding which bind to which should bring tremendous new power to the field of life sciences. Bamdad thinks her nanoparticle probes are ideally positioned to solve gigantic chunks of the problem because of their ability to yield information about how proteins bind together.

Bamdad believes her biosensors have virtually unlimited applications across the entire health-care and biotech industry, but ironically, the broad diversity of the technology's commercial opportunities presents a particularly thorny problem. Because of Minerva's own nano size (just Bamdad and six researchers), the company has to prioritize its efforts carefully lest it spread its resources too thin. While Bamdad's record at the track has helped her to raise $3.5 million in angel investment, as well as $3.2 million in government research grants, groundbreaking biotech research is extremely expensive, and Minerva's initial capital has been largely consumed getting the company to the stage where it can attempt to commercialize its intellectual property.

Pursuing each of Minerva's potential markets will require significant funds—running clinical trials for a new cancer therapy, for example, can cost millions—and Bamdad plans to defray these costs by forming partnerships with much larger biotech companies, which would share the investment in exchange for favorable terms in licensing Minerva's intellectual property. Minerva, which has dozens of patents pending, would receive licensing revenue from its original partners and, hopefully, from other companies that would subsequently compete in their markets. Nonetheless, the biotech-startup graveyard is choked with companies whose laboratory successes failed to convince customers to open their wallets, and there is every reason to believe that Bamdad's hopes will not entirely pan out.

Cynthia Bamdad is a woman with a plan.

Having multiple markets to pursue can be an advantage in that it provides more baskets for one's eggs, but business partnerships can be maddeningly time-consuming to negotiate and even worse to manage and maintain. Large companies can easily overwhelm smaller partners with their standardized business processes—by assuming, for instance, that their partners have as many employees available to answer phones as they have available to make calls. Handling several business lines requires a level of managerial maturity that most small companies lack. In Minerva's case, I suspect it will have to focus on a primary initial market that can validate the commercial viability of its technology and blaze a trail for follow-on applications.

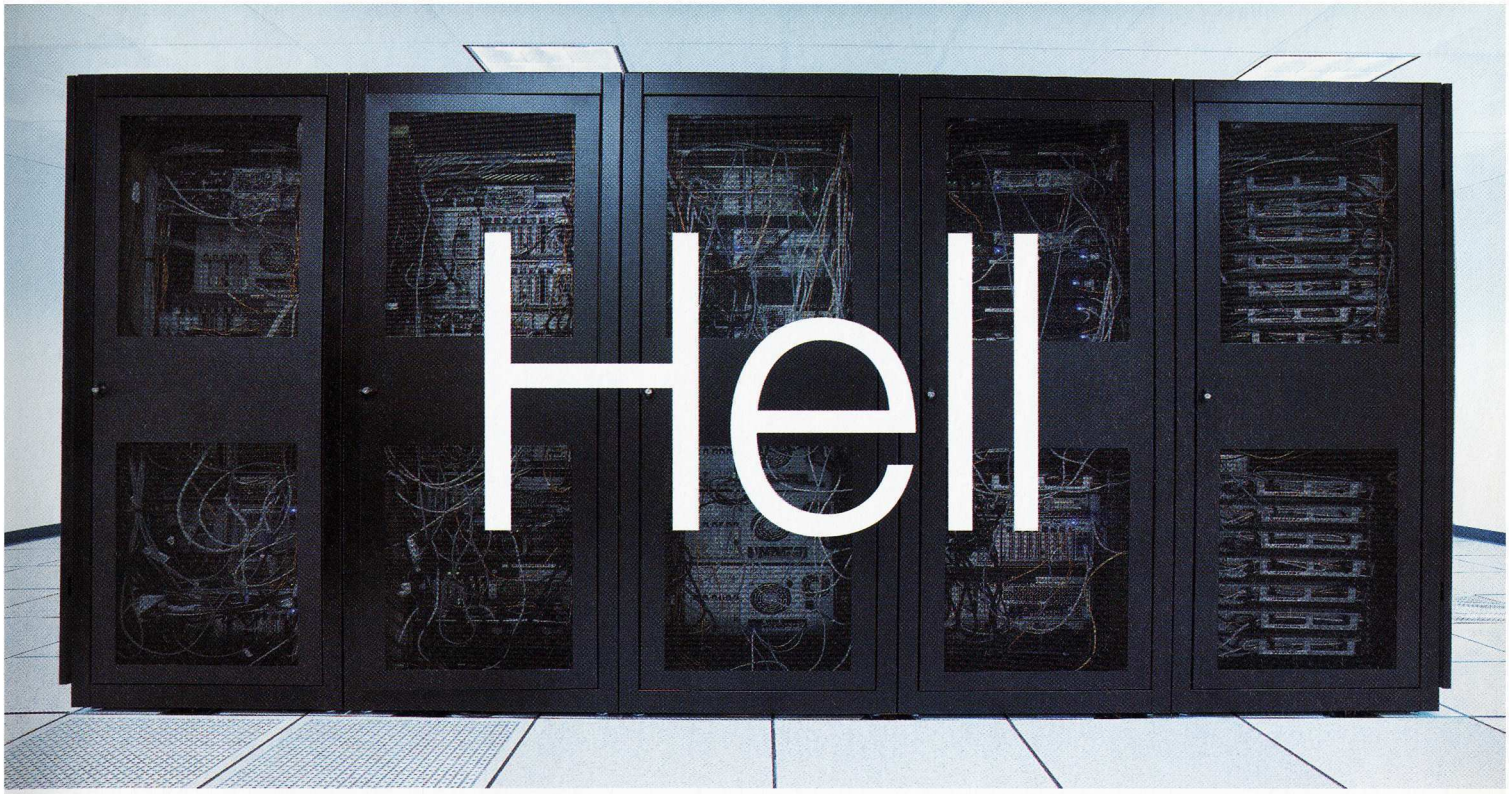
Still, having too many potentially profitable businesses is a far better problem than having too few (or none at all, as is the case with many contenders). And if Bamdad is even half right, her technology will have a profound impact on our lives even if she doesn't immediately provide a cure for Alzheimer's disease or breast cancer. And if she's more like 80 or 90 percent right, then Minerva's biosensors may well be the key that unleashes a new wave of biotechnology miracles.

Sound good to you? It sounded pretty good to me too, but please bear in mind that although I have two degrees from MIT, neither of them is remotely related to biotechnology, and I have no way of objectively assessing Minerva's inventions or comparing them to the competition's. When considering investing in a highly technical startup, one should seek the opinions of actual experts; but at the end of the day, it's still a fundamental bet on the credibility, prowess, and drive to win, no matter the obstacles, of the jockeys.

As for Bamdad's very first stallion, I asked her when she plans on replacing her Ferrari. She answered with deadpan nonchalance, "Oh no, I've moved on from those days. And anyway, I drive a Porsche." Not bad for Plan B.

Joe Chung cofounded Cambridge, MA-based Art Technology Group. Neither he nor *TR* holds any financial interest in the companies profiled nor endorses them as investments. To share your company's story with Joe, e-mail joe.chung@technologyreview.com.

CAROL PALMER



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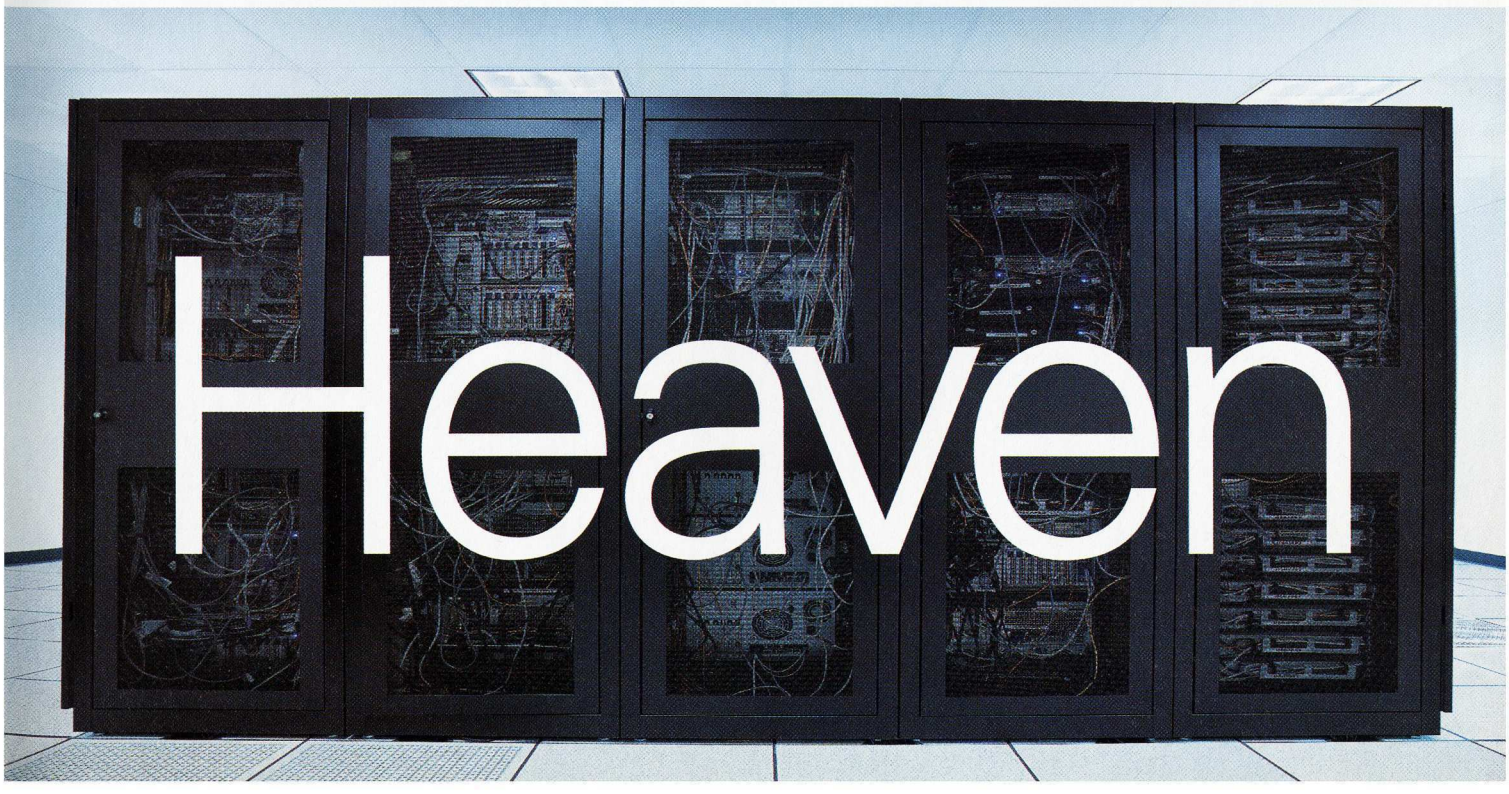

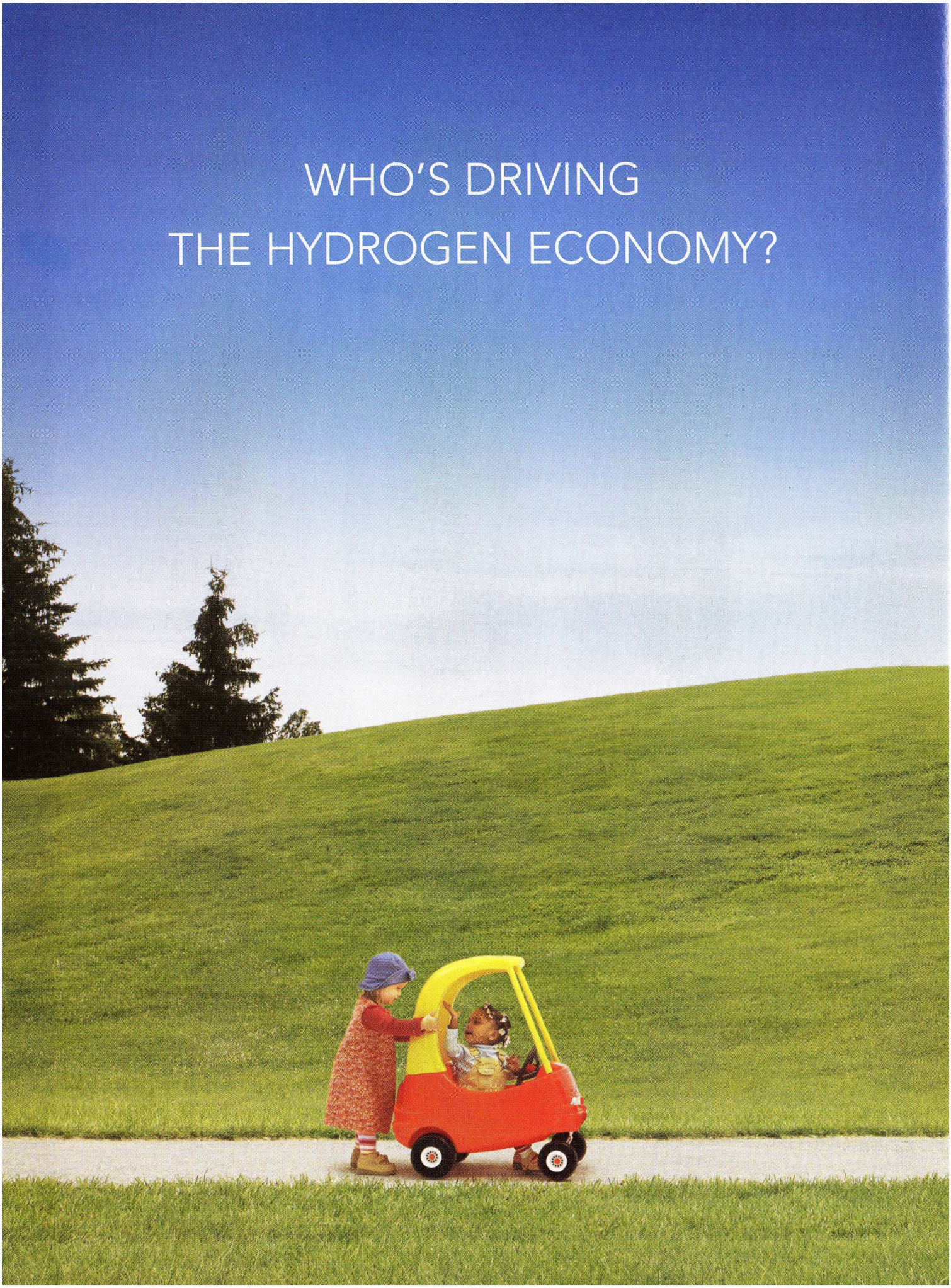
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THE HYDROGEN ECONOMY?

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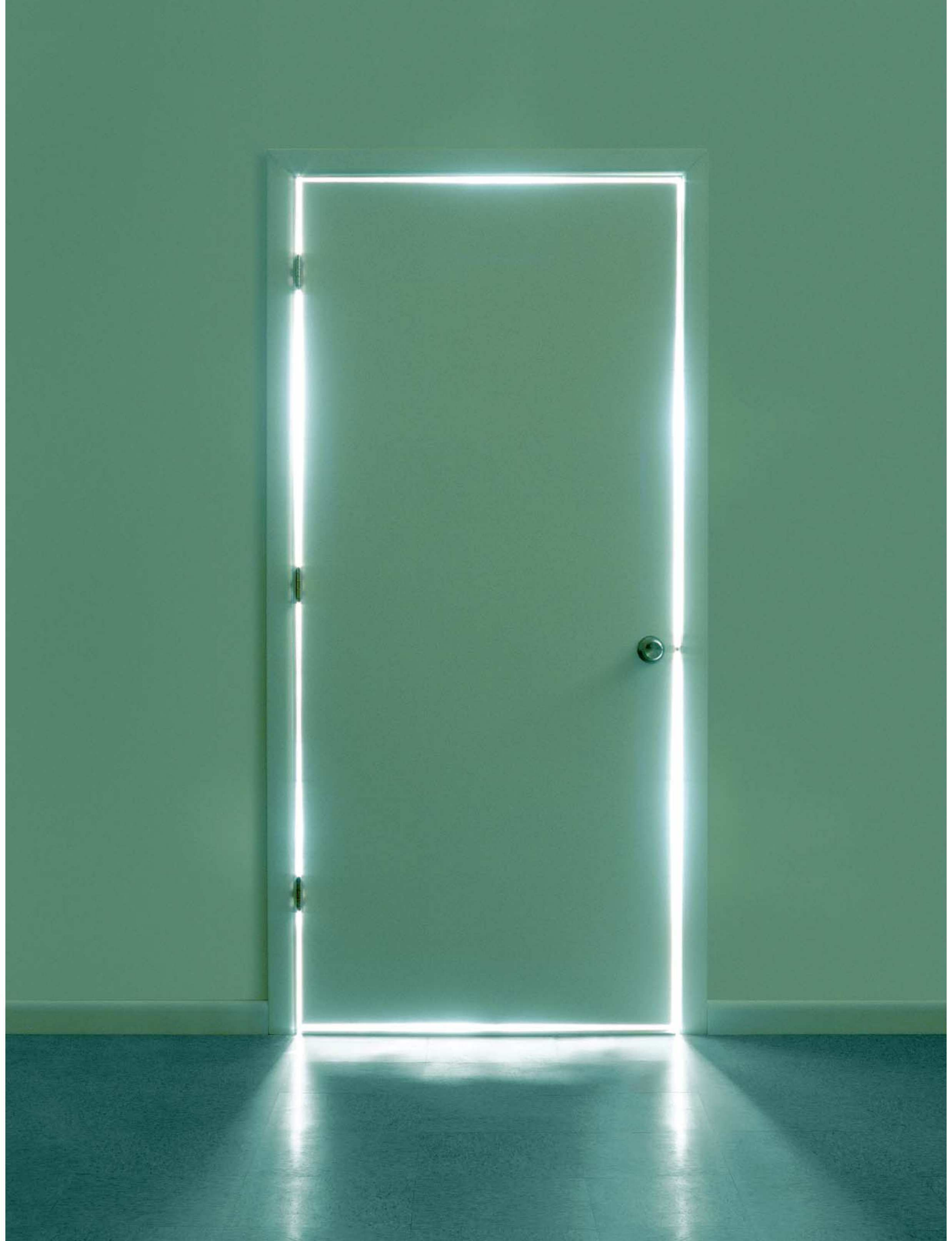
SPARKING THE FIRE OF INVENTION

ONE OF THE MOST RADICAL BUSINESS IDEAS OF THE 21ST CENTURY MAY BE THE CREATION OF A NEW METHOD OF INVENTION—INDIVIDUALISTIC, GLOBAL, AND NOT BOUND TO CORPORATE MISSIONS.

BY EVAN I. SCHWARTZ PHOTOGRAPH BY FREDRIK BRODEN



NATHAN P. MYHRVOLD HAS NO INTEREST IN COMPETING WITH MICROSOFT—BUT HE DOES MEAN TO CHALLENGE THE VERY METHOD OF INNOVATION PRACTICED AT THE COMPANY HE LEFT FOUR YEARS AGO.

The 44-year-old founder of Microsoft Research and former chief technology officer of the Seattle giant argues that virtually all big corporations, even wealthy ones, lack motivation to pump money into projects outside their existing product lines. In other words, they tend to discourage *invention*, the often subversive effort to isolate new problems and generate unexpected solutions. "Invention is a side effect [at corporate labs], not the focus," Myhrvold says. "Most large organizations have a mission, and invention often takes you in another direction. When it comes to mission versus invention at most companies, mission wins." Even small companies such as Silicon Valley startups, he notes, are often loath to support invention outside their core markets.

Yet this very reluctance has opened a world of opportunity, Myhrvold believes. "You can't outdevelop Microsoft," he says. "But you can out*invent* Microsoft."

And that's exactly what Myhrvold and former Microsoft chief software architect Edward Jung have set out to do at Bellevue, WA-based Invention Science, a hothouse of ideas where staff have free rein to cross-pollinate insights from information technology, biotechnology, and nanotechnology—three domains that Myhrvold feels are converging to make powerful new technologies possible. In recent months, the organization has quietly hired some two dozen inventors, along with the patent attorneys and licensing experts needed to support them and get their ideas to market. It's the culmination of more than two years of travel, study, and planning by Myhrvold and Jung, who first set up an independent Bellevue research shop called Intellectual Ventures in 2000 *(see "The Invention Factory,"* TR *May 2002)*. The company serves as the parent for Invention Science.

The new venture, Myhrvold says, has no mission other than to invent what the inventors believe should be—or can be—invented. "Invention is the secret sauce," Myhrvold says. "It has the highest concentration of value compared with any task in a company. But because it's so risky, it also has the lowest amount of focused effort." Showing what can happen when that effort is intensified is Myhrvold's main reason for creating the laboratory, which he is funding in part from his own Microsoft-made fortune.

MILESTONES

1940

The U.S. Census Bureau eliminates "inventor" as a separate job category.

Myhrvold isn't the only one to see new value in cross-disciplinary collaborations where invention itself is the primary goal. In fact, more and more ventures dedicated solely to invention have been popping up in recent years—including Walker Digital, a business systems developer in Stamford, CT, and Invent Resources, a small Lexington, MA, consultancy whose slogan is "Invention on Demand" *(see "Independent Inventors Incorporated," p. 38)*. And the mindset is spreading to the corporate world as well: at research-driven companies like brainstorming firm Generics Group of Cambridge, England, engineers are actually paid to spend a subset of their time on personal projects, stuff that typically has little or nothing to do with what their clients are doing—yet. Even young firms like Google, in Mountain View, CA, are getting into the act: the search engine leader encourages employees to devote 20 percent of their time to developing their own far-out ideas. The belief at such companies is that creative people are fueled by freedom to find problems that interest them. "Our employees are coming up with ideas anyway," says Google cofounder Sergey Brin. "We just provide them with time to test whether those ideas work."

This freedom to pursue invention for its own sake is the main hallmark of today's climate. It's been argued that moments of invention are little different from the rest of the research and development process—they are simply a matter of applying "normal problem solving to the right problem space," says David N. Perkins, a principal investigator at Harvard University's Project Zero, a 35-year effort to understand human creativity. But a close look at the process of invention reveals that some problems are so hard that they're "unreasonable" to even consider during the normal R&D process—or worse, they're completely hidden. Dedicated inventors "can recognize latent opportunities, problems that people don't even know they have," Perkins says.

No one personifies this mindset more than Myhrvold. As the affable, bearded physicist, photographer, and paleontologist flew around the world in his Gulfstream V jet attempting to get into the heads of inventors young and old, he became convinced that a new global flowering of invention is possible. For one thing, he says, the Web and other powerful information technologies make sharing knowledge easier than ever, enabling people with great ideas to attract capital and marketing firepower more readily. Meanwhile, the very pace of technological progress is picking up. Myhrvold foresees what he calls a new age of exponential growth, in which converging technologies will bring unpredictable but important changes—at a pace comparable to that of microchip miniaturization, famously described by Moore's Law. But what inventors require to generate this kind of growth, he concluded, is focused, long-term support, like the access to patent and licensing experts he and Jung are providing to their staff.

Ultimately, Myhrvold and others funding pure invention are out to debunk the perception that research labs make sense only when they are part of an existing corporate structure—one that

"You can't outdevelop Microsoft. But you can out*invent* Microsoft," says Nathan Myhrvold.

ANDY FREEBERG

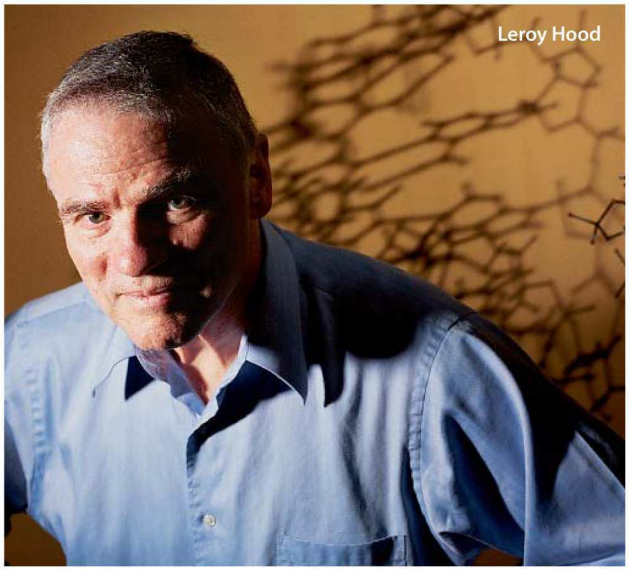
includes development, manufacturing, distribution, and marketing. Until the 1980s, Myhrvold points out, businesses had a similar attitude toward software, believing that it was only valuable when bundled along with hardware. Bill Gates and others thoroughly disproved that theory. In the same way, "We think invention can be valuable in and of itself," says Myhrvold.

"Invention is the new software."

MORE POWER TO THE LITTLE GUYS

The new climate for invention, say Myhrvold and others, is the result of four major trends. The first is the reemergence of invention outside big corporations. For nearly a century, the innovations of large corporate research centers such as Bell Labs or General Electric overshadowed those of inventors working alone or in small groups. But now a constellation of forces is bringing the individual inventor and small technology companies—and sometimes small teams within large firms—back to the fore.

The change marks a comeback for those iconoclastic souls who still call themselves inventors—the people considered the driving force of the economy in the days of Thomas Edison, Alexander Graham Bell, and the Wright brothers. From the 1920s and '30s onward, with the rise of giant technology-based companies like GE, AT&T, and DuPont, invention became coopted by corporate labs that had to answer to management hierarchies. Within corporate labs, inventors were reclassified as "researchers." In 1932, the year after Edison died, more U.S. patents were granted to corporations than to individuals for the



REINVENTING BIOLOGY, VIRTUALLY

Elite researchers team up across institutes to create a powerful biotech tool

Sometimes, thinking big means thinking small. For an audacious collaboration known as the Nanosystems Biology Alliance, the goal is nothing less than to invent a "nanolab," a chip one centimeter square that can sense 10,000 different proteins and other molecules in a single blood cell, looking for signs of impending disease and helping to identify malfunctioning molecular pathways that could be regulated with drugs.

Reaching that goal will require a combination of advances in nanotechnology, microfluidics, and "systems biology," which views cells as if they consisted of vast chemical circuits. So the alliance is thinking big as well: it includes researchers in eight labs at three West Coast scientific institutions.

To cofounder Leroy Hood, the alliance represents how it's possible to push the boundaries of invention by bringing top inventors together—even if they're separated by geography. "If you want to solve a problem, why not get the best people together to work on it?" says Hood, who is also president of Seattle's Institute for Systems Biology.

The alliance's elite eight include people like James Heath, a Caltech chemist and nanotechnology pioneer; Michael Phelps, a University of California, Los Angeles, scientist who coinvented positron emission tomography (PET); and Hood himself, the coinventor of the automated DNA sequencer. Hood's hope is to combine the group's mental firepower to build a handheld device that could detect everything from the early signs of cancer to the molecular changes associated with heart disease.

Financing their work from existing academic grants, the alliance members have spent most of the last year learning about each other's fields, trading postdocs, and exchanging lots—*lots*—of e-mail. But the alliance "is not completely virtual, or it would not work," says Heath. He and the members of his Caltech group visit Hood's lab frequently and swap equipment and materials. Also helping to keep the whole extended collaboration together: "We have a strong and shared vision of where we want to go," Heath says. "That drives everything." WADE ROUSH

first time, and in 1940, the U.S. Census Bureau eliminated "inventor" as a job category.

At big companies, the emphasis gradually moved from invention to what legendary economist Joseph A. Schumpeter called the second and third stages of technological change: *innovation*, in which ideas are transformed into marketable products and services, and *diffusion*, which sees those products and services distributed across markets. Companies adopted the view that invention by itself was only a tiny part of business success; for every $1 spent on basic research, the conventional wisdom went, $100 would be spent on development and $1,000 on commercialization. Since great ideas often fail, and the best or most original product doesn't necessarily win in the marketplace, the inventor came to be perceived as a relatively minor player in the equation. The dot-com boom of the late 1990s skewed this model to new extremes, as billions of dollars were staked on the conviction that the Web was changing everything about commerce, without much in the way of marketable inventions.

Now, with big corporate research laboratories focusing more and more on shorter-term product cycles, many see a growing opportunity for small companies, academic researchers, and individual inventors to generate breakthroughs that have longer-term impact. Anthony Breitzman, vice president of CHI Research, a Haddon Heights, NJ, patent analysis firm, reports that big corporations still have a wide lead in patent filings, especially in areas such as aerospace, motor vehicles, oil and gas, computing, and plastics, where research is expensive and small companies don't have the resources to compete. But Breitzman notes that "there *are* areas where small companies are really competing." In biotechnology, pharmaceuticals, and medical electronics—fields where every company is drawing on the same base of knowledge about the human body and the genome—about 25 percent of patents are being issued to small companies and individuals *(see "Reinventing Biology, Virtually," this page)*. A disproportionate number of those are "high-impact patents," Breitzman says, inventions that actually do become significant products in the marketplace.

The second trend: burned by the often vague schemes that passed for breakthrough thinking in the late 1990s, venture capitalists, in particular, have become far more selective, often insisting that the companies they back have significant, patented inventions that will shield their investments from competition. Attention to invention is becoming more rigorous across all areas of technology, says MIT engineering professor David Staelin. Staelin cofounded an MIT venture mentoring program that currently advises about 70 student- and faculty-led startups; he says 85 percent of the companies were formed around patentable inventions, from a smart golf club that tells users how to improve their swings to exoskeletons that help people in rehab.

The new emphasis on invention pays off. CHI Research combs patent databases for "highly cited" patents, ones that are frequently referenced in papers and later patents. According to CHI, the stocks of companies with a high proportion of these highly cited patents have greatly outperformed both the S&P 500 index and the stocks of companies with low num-

MILESTONES

1981

In *Diamond v. Diehr*, the U.S. Supreme Court rules that software can be patented.

BRIAN SMALE

Middleware	Key
1. Instantly admitting patient.	
2. Immediately processing claim.	
3. Automatically approving procedure.	
4. Constantly tracking treatment.	
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bers of highly cited patents *(see "Investing in Invention Pays Off," this page)*. "Highly cited patents correlate to [stock market] success," says Breitzman.

INVENTING LOCALLY, MARKETING GLOBALLY

Thirdly, the Internet and other ubiquitous communications tools are enabling new global connections. Inventors everywhere are able to not only access patent databases, troves of online technical specifications, and genomic repositories but also take advantage of e-mail and collaborative software tools to brainstorm across borders and tap international markets. A record 49.9 percent of U.S. patents awarded in 2003 listed at least one non-U.S. citizen as a coinventor. Foreign entities will likely account for the majority of U.S. patent filings from 2004 onward, predicts CHI's Breitzman. Some two dozen countries now produce significant levels of U.S. patents per capita, a figure that is highly correlated with higher GDP and standards of living *(see the Global Invention Map, p. 76)*.

For high-cost nations like the U.S. and Britain, this worldwide competition—which is intensifying as other countries beef up their educational systems and intellectual-property protections, and firms outsource high-tech jobs to lower-wage regions—means that professionals must prove their worth by moving up the intellectual-property value ladder. Instead of just completing assignments that are handed to them, employees need to be more inventive and more original in their thinking—often by finding new problems to tackle in the first place. Former U.S. labor secretary Robert Reich, now a professor at Brandeis University, identifies two growing categories of work in today's economy. The first he calls "symbolic analysis"; it involves the application of in-depth knowledge and includes jobs in R&D, design, and engineering. The second is "personal services" such as those provided by retail clerks, security guards, and hospital attendants. "Only the first [category] is commanding better pay and benefits," Reich notes. "This category includes identifying and solving new problems." In a nutshell, that's exactly what inventors do.

INVESTING IN INVENTION PAYS OFF

Companies holding patents that are cited most frequently by papers and other patents and that yield marketable products the fastest have far outperformed the S&P 500. This chart depicts the successive year-end values of $1,000 initially invested in January 1990.

The leveling of the international playing field enhances the long-standing premium on original thinking, and smart companies are becoming more and more open to licensing inventions from smaller competitors, wherever they may be. "We're scanning the horizon for new ideas outside the company," says Simon Beesley, professional-audio marketing manager for Sony Professional Services Europe, a 1,200-employee division of Sony. "We're not as closed as we were ten years ago." He cites as an example the company's rollout of Hypersonic Sound, a directional-audio system developed by U.S. inventor Elwood "Woody" Norris *(see "The Sound War," p. 50)*. Sony is bundling the invention as part of plasma screen audiovisual systems. But Beesley says it is also selling the technology to dozens of retailers, banks, and museums across Europe that are "clamoring" to build products, machines, and exhibits that can beam audio narration or marketing pitches to one customer at a time. "Every time I show this to someone," Beesley says, "they come up with a new idea for using it."

INDEPENDENT INVENTORS INCORPORATED

A sampling of companies and organizations that exist chiefly to incubate new inventions—often for hire

ORGANIZATION	ORIGINS	DESCRIPTION	SAMPLE INVENTIONS
Invention Science Bellevue, WA	Started by former Microsoft executives Nathan Myhrvold and Edward Jung	In-house inventors explore convergence of information technology, nanotechnology, biotechnology; 25 employees	New types of lasers
Walker Digital Stamford, CT	Launched in 1999 by Jay Walker, creator of priceline.com	Develops and licenses business-related technologies; 40 employees	USHomeGuard, a system of surveillance webcams and civilian spotters
Invent Resources Lexington, MA	Formed in 1992 by former MIT physicist Richard Pavelle and electronics engineer Sol Aisenberg	Consults with clients to test ideas and develop prototypes; four employees	Electronic time stamp; advanced microwave ovens
Generics Group Cambridge, England	Established in 1986 by electrical engineer Gordon Edge	Brainstorms new products and consults with clients on development; more than 200 employees	Advanced fuel cells; strong cardboard can for carbonated drinks
Sarcos Research Salt Lake City, UT	Created in 1983 by roboticist Stephen Jacobsen	Develops products for government and commercial clients; 50 employees	Robotic arms and hands for industrial and prosthetic uses
Deka Research and Development Manchester, NH	Launched in 1982 by independent inventor Dean Kamen	Develops products to improve patient quality of life and increase mobility; 200 employees	Home dialysis machine; stair-climbing wheelchair; Segway human transporter

SOURCE: CHI RESEARCH (INVESTING)

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PEERING INSIDE INVENTION

That fits with the final trend—toward a new appreciation of how the cognitive process of invention actually works. Invention is so steeped in the myth of accidental discovery that one might conclude it's like playing the lottery. For example, there is the tale of Percy Spencer, the researcher at Waltham, MA-based Raytheon who reportedly noticed that a radar tube in his lab melted the candy bar in his pocket—resulting in the microwave oven. Chance can indeed be a key element of invention. But from their studies, Myhrvold and others have come to realize that truly "accidental" inventions are rare and are usually exaggerated in hindsight—sometimes to justify why researchers deviated from what they were supposed to be doing. Most of these stories leave out the fact that these researchers were keenly observant and were deliberately trying to invent new things all the time.

MYHRVOLD AND THE INVENTION FACTORY

Q&A with the former Microsoft mogul

TECHNOLOGY REVIEW: What kinds of inventors have you hired?

NATHAN MYHRVOLD: We have a staff of 20 to 25 people, plus 10 or 15 outside affiliated inventors. Lots of fantastic people. One reason they're successful is that they have a giant experience base. A large fraction of our inventors are women. At one brainstorming session, we looked around and noticed that men were in the minority, and that white men were in the minority among the men.

TR: How many inventions are you currently working on?

MYHRVOLD: We have many hundreds of ideas under investigation. We invent in solid-state physics, in electronics, in software, nanotech, biotech, biomedical. We're about following our inspirations, as opposed to working on any preordained problems.

TR: Are there any good models for Invention Science?

MYHRVOLD: The model for what we are doing now was set in the 19th century. Edison and Bell and Tesla and lots and lots of others had invention-oriented businesses back then. Invention was a big thing. The world is due for this to come back.

TR: Do you foresee competition?

MYHRVOLD: We'd welcome competition. We hope our inventions spawn other inventions. I hope there are people who get fantastically wealthy building on our ideas. There is a real opportunity for small groups of people to make incredible contributions. Silicon Valley and Wall Street will rise to the challenge if great new ideas are created.

TR: What didn't you know when you started your invention lab?

MYHRVOLD: What has surprised me most is how well we have been able to get inventors to play off one another and collaborate in brainstorming. We have a couple very exciting inventions involving new kinds of lasers. If you asked me if we could have done that, I would have said no two years ago. I would have even said no before going into the sessions where we invented these things. I had the key idea on both. But one person can provide only 25 percent of the bridge across the Grand Canyon. That's only enough to get you to fall to the bottom. You need lots of help. If you can get a rapport going among inventors with different backgrounds, you can accomplish amazing things. **EVAN I. SCHWARTZ**

In fact, invention is now being recognized as a more focused, deliberate process, enacted by people who are especially good at finding new problems and who often work and think differently from typical researchers and technicians. Sarcos Research of Salt Lake City is a case in point. The 50-employee invention shop, which CEO Stephen Jacobsen calls a "skunk works for hire," develops prototypes and licenses them to firms such as Merck, Pfizer, Disney, Sony, Lucent, and the Palo Alto Research Center.

MILESTONES

2004

U.S. patent filings from foreign entities are expected to surpass those from U.S. entities for the first time.

By mixing ideas from biology and engineering, Sarcos's researchers have built everything from high-precision catheters for maneuvering inside the bloodstream to robot dinosaurs for Hollywood. But Jacobsen himself—the inventor of the Utah Arm, the world's most advanced robotic arm replacement for humans—may be the company's most unconventional thinker. Visual representations preoccupy Jacobsen to such an extent that he says he has virtually no recollection of nonvisual data, such as dates. He visualizes the progression of the hundreds of inventions he has worked on in terms of how their intricate shapes were formed and assembled over time. After enlarging a device such as a microchip or a nanosensor in his mind and setting it spinning and twisting, he can go about constructing it and writing the software for it. "What I remember is the geometry," he says.

Few people may think as visually as Jacobsen, but everyone can be more inventive, the experts say. "We've got a prefrontal cortex that works as an experience simulator," says Harvard psychologist Daniel Gilbert. "We can have experiences in our heads before we try them out." With practice, just about anyone can learn visualization and other high-level thinking skills that help to create new concepts and translate them into practical technologies, Gilbert says. Inventor Jay Walker—the founder of Walker Digital, the creator of priceline.com, and the holder of more than 200 business process patents in industries ranging from retail to gaming to health care—agrees. "Can anyone learn to do improv, or to become a pianist or a chef or a wine taster?" he asks. "Sure. Anyone with above-average intelligence can do those things. But it takes years and years to train your brain to do it well. Invention is the same way."

So in addition to leaping across disciplines and challenging assumptions, inventors visualize results and embrace uncertainty—which is another reason a bigger proportion of invention may be taking place outside the traditional corporation. "All the conventional wisdom works against invention," says Walker. "The field of management is about reducing the risk of bad outcomes involving people; the field of engineering is about reducing the risk of bad outcomes involving technology. But invention is about taking risks that will almost certainly fail in order to find the unlikely breakthrough."

By that logic, brainstorming laboratories like Myhrvold's Invention Science are almost certain to produce lots of failures—but also, perhaps, the occasional big idea that changes the world…and later gets called an accident. TR

Evan I. Schwartz is a *Technology Review* contributing writer and the author of *Juice: The Creative Fuel Driving Today's World-Class Inventors*, forthcoming in September.

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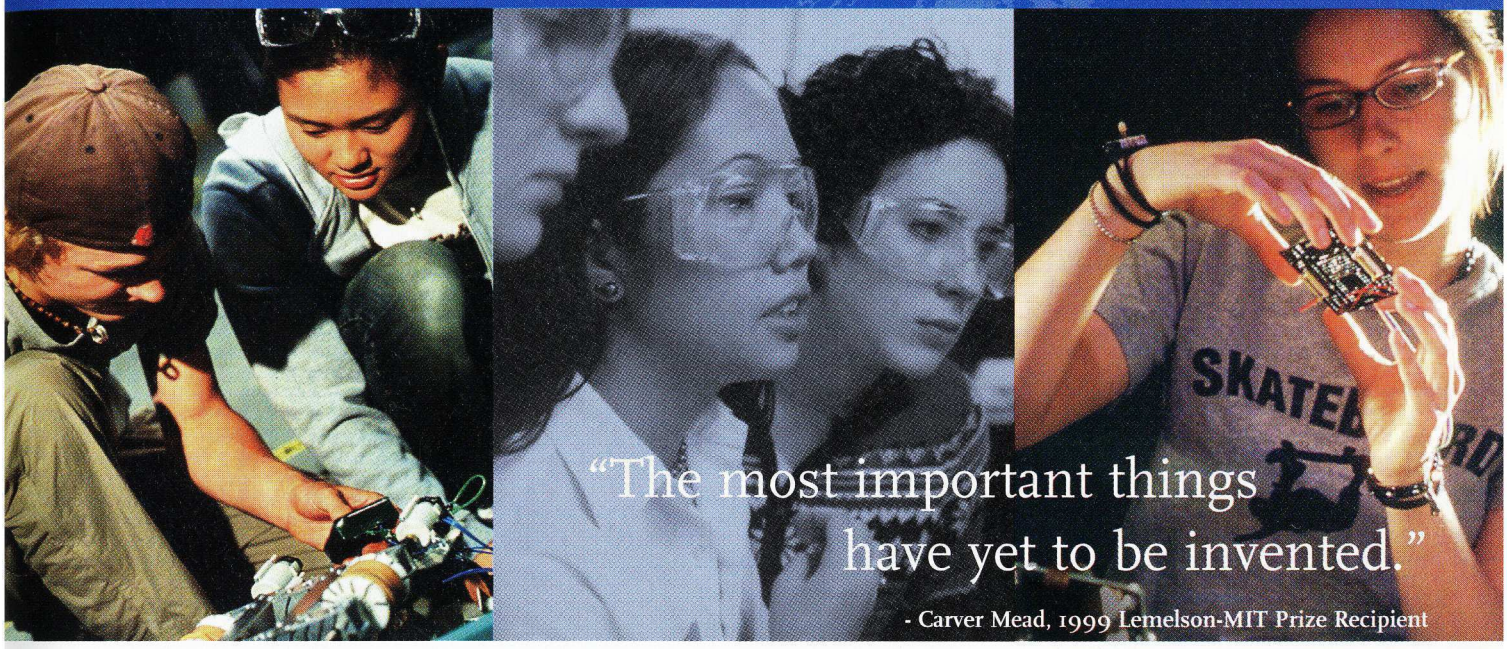

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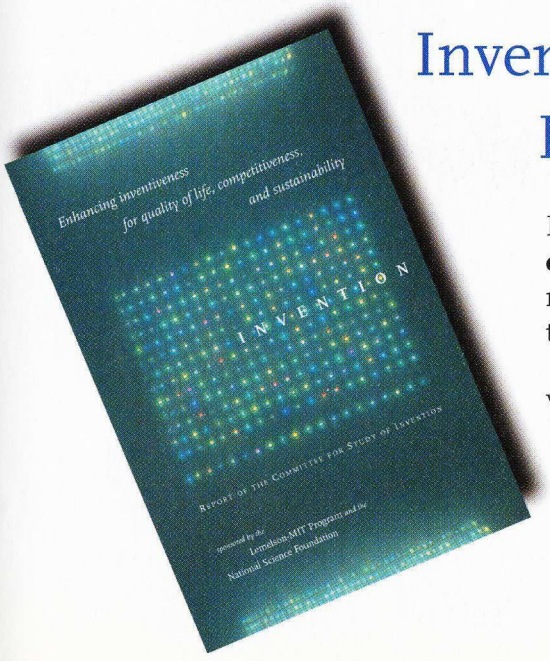

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WOZ GOES WIRELESS

STEVE WOZNIAK, COINVENTOR OF THE FIRST APPLE COMPUTER, HAS COME UP WITH A CHEAP WAY TO KEEP TRACK OF PETS, KIDS, AND ANYTHING ELSE WITH THE TENDENCY TO STRAY USING WIRELESS NETWORKING AND THE GLOBAL POSITIONING SYSTEM. BY MICHAEL A. HILTZIK PHOTOGRAPHS BY EMILY NATHAN

STEVE WOZNIAK
COMPANY: Wheels of Zeus
INVENTION: GPS tracking
MOTIVATION: Lost dogs
VISION: Inexpensively combine GPS and wireless networking to tell you where your children, pets, and valuables are

THE OFFICIAL ORIGIN legend of Steve Wozniak's newest company, Wheels of Zeus, will hold that its core invention grew out of Wozniak's attempt to keep track of his dogs after too many electronic fences had failed to do their job.

"I had a few periods of shock," he explains, "of finding that somebody had found my dog along the way. But what really intrigued me was the idea that this was doable technically." The legendary inventor is referring to his latest idea: putting Global Positioning System technology to work around the home. GPS and radio chips had become so inexpensive, Wozniak says, that they were crying out for new uses. "I had enjoyable thoughts," he says, "about a product category that hadn't occurred to me before."

That category might be called networked GPS: allowing people to attach inexpensive and unobtrusive global-positioning devices to their children, pets, elderly relatives, cars, or anything else that could end up in an unsafe, inappropriate, or unauthorized place, and keep track of them via a wide range of wireless applications. The devices, for instance, could alert your PC, home telephone, cell phone, or personal digital assistant when your child made it to his or her destination, or when your dog wandered off your property. "If your pet escapes while you're at work, you'll get a phone call promptly," says Wozniak during an interview at the Los Gatos, CA, headquarters of the company he founded in October 2001. "Then you can track it precisely with a device in your hand." The name Wheels of Zeus was chosen partially for its acronym: a generation of computer enthusiasts knows "Woz" as the technical genius behind the first Apple personal computer.

Although Wheels of Zeus has attracted about $9.7 million in two rounds of venture investments, the basic idea of linking GPS with wireless communications is not in itself new. Subscription services such as uLocate in Newton, MA, have already sprung up to exploit a government requirement that new cell phones incorporate GPS. These services charge a fee to activate the GPS function for individual subscribers. Other companies, like Redwood Shores, CA-based Wherify, sell portable GPS devices, some designed specifically to be worn by kids. But these generally sell for more than $100 each.

Wozniak's idea is more ambitious and more homely. The Wheels of Zeus devices will do less than GPS-equipped cell phones; they probably won't make and receive calls, for example. But Wozniak aims to push their cost down to the point where a subscriber might deploy ten instead of one or two. Rather than yoking the devices to a cellular network, as Wherify does, Wozniak intends to build a low-speed, low-power network that will relay their GPS data to end users. This wOzNet, as he calls it, would stitch together local "hot spots," each with a range of about three kilometers, similar to public Wi-Fi nodes. One idea is that every user's base station will function as a node for other users in a neighborhood, leading to what one investor calls "an instantaneous self-deploying network": as more customers sign up, the network becomes progressively more powerful.

Wheels of Zeus hopes to make money both by licensing its technology and by collecting subscriber fees for the use of its location service. In January, Motorola became the first licensee, with plans to manufacture and distribute the hardware necessary to make wOzNet functional. Still, by late winter it was unclear when the first-generation product might hit the market. "It could be out this year," Wozniak says.

So basically, Wozniak is trying to make a complicated set of technologies accessible to a broad market. He's been there before.

RELENTLESS PURSUIT OF SIMPLICITY

The conception and gestation of Wheels of Zeus typifies Wozniak's modus operandi throughout his storied career. First, he notices that a technology has become cheap enough for the mass market; then the possible applications suggest themselves. The same intuition drove Wozniak's initial Apple designs, starting with the hobbyist-oriented Apple I.

Now 53, Wozniak is still recognizably the bearded, burly boy wonder who appeared at the Homebrew Computer Club in the mid-1970s armed with a formidable and seemingly intuitive talent for engineering. His office at Wheels of Zeus hints at his devotion to cleverly engineered gadgetry, with pride of place along one wall awarded to a Segway scooter, the latest creation of his friend and fellow inventor Dean Kamen.

On his personal website and on paper, Wozniak projects warmth and openness. In person, he's more serious and more focused, given to bemoaning the time pressure imposed by the countless questions and requests e-mailed every week by his legions of admirers and acolytes. Ask him to opine on the broad issues of innovation and invention or to analyze his own life, and he widens his eyes in surprise and apprehension as though the subjects have never occurred to him before.

In part, Wozniak attributes his technical skill in electronics to his upbringing as the son of a Lockheed engineer deeply involved in the fledgling semiconductor industry—not as a designer of chips, but as a user of them. "My father was involved in the first applications of semiconductors for missiles, where things had to be so lightweight," he says. From the start of his career, Wozniak was known for his mysterious genius for paring a schematic down to its essentials—without sacrificing performance. "Even when I was in sixth or eighth grade, I understood that efficiency is output over input," he says. "And efficiency is what drives technology in the world."

WOZNIAK IS MAKING COMPLICATED TECHNOLOGY ACCESSIBLE TO A BROAD MARKET—AGAIN.

This was during the late 1960s and early '70s, when a pioneering generation of computer architects was starting to consider the implications of the plummeting cost of computer resources. Wozniak, who hadn't yet finished college when he completed his earliest designs for Apple, didn't concern himself with formal theory. He just noticed that chips were getting better and better every six months—and reacted. "Whenever I saw a new and better chip, I asked myself how I could apply this to do a prior design with fewer parts."

Wozniak's immediate goal was always to create a smaller, faster, lighter design; "Woz's Law" might be expressed, in his own words, as "low cost, always." He had trained himself for this relentless pursuit of simplicity by years of solitary study, which he viewed as a competition with himself. "That's why I got so good that nobody could ever match my skills—nobody I ever ran into. It was just a game. You just work harder and harder, and

your brain thinks deeper and deeper, and you know when you've won because you've done something with fewer parts and fewer lines of code. Competing with another person doesn't have the same result, because if you're competing with a person and you do a better job than he does, you say, 'I've won.' You don't go back and say, 'How do I do it better yet?'"

But Wozniak also came to see that the trade-offs from a smaller design at some point won't be worth the gain. "There were levels when a design could be fewer parts but cost more money, or require fewer parts but bigger parts, or fewer parts but more connections," he says. "I learned that the number of connections was much more important than the number of chips, for reliability and for real simplicity."

Wozniak understood, furthermore, that smaller and cheaper devices brought value to ordinary people. "When can useful things be built for a low cost?" he asks. For him, much of the charm of Wheels of Zeus's radio-networked GPS technology is that a home system might be marketable for a few hundred dollars.

PRANKSTER AT PLAY

The principle of delivering value to ordinary consumers has driven virtually every project Wozniak has embarked upon. Perhaps the most famous expression of that principle was Wozniak's design for the Apple I, which he introduced at the Homebrew club in early 1976. Built around a microprocessor that Wozniak selected because it cost only about $20, the machine was in its first incarnation a schematic diagram that indicated interfaces for a keyboard and a television that would serve as a display. At the club, Wozniak passed around copies of the schematic, which was so simple that almost any member could build from it.

Balancing the idea of a computer with functional utility was Wozniak's desire for a machine that would be adept at games. He was, after all, a renowned local prankster. As a young man, he had hand-built "blue boxes" to fool AT&T switches into patching people into long-distance circuits for free, and his narrowcasting of Polish jokes from his answering machine had evolved into a dial-a-joke service of Bay Area legend. He had also refashioned Atari's signature game Pong into the more advanced Breakout in four days, at the behest of his friend Steve Jobs, then a consultant at Atari.

Pet project: Tired of losing his dogs, Steve Wozniak invented a GPS-enabled network to track their wanderings.

Wozniak acknowledges that he has tended to thrive most in environments where he is free to please himself, as during the earliest days at Apple: "If I discovered that the PC layout could be more efficient if the design were different, I had the freedom to change the design." That sometimes means he runs ahead of whatever group he is in. Unlike the rest of the Homebrew bunch, for instance, he was a fan of dynamic random-access memory, or DRAM, which reached the market around 1970. DRAM was cheaper than the more common static RAM and more efficient—the Wozniak grail. But it required a much higher level of engineering skill than most hobbyists had, so Wozniak found himself out on a technological limb. The past 30 years of PC evolution have vindicated him, as DRAM has become by far the most common form of computer memory.

Wheels of Zeus gives Wozniak the same kind of autonomy he initially enjoyed at Apple. As its founder, he is fond of saying that the company started as "just a cool concept: GPS for knowing the location of things remotely." But the essence of the idea remains recognizable as basic Woz: GPS in a package that would be "smaller and more mobile and cheaper, and at human prices." Still, that it's clever and intriguing is an essential part of the allure. Says Wozniak, "The goal is doing something neat and fun."

Since leaving Apple in 1985, Wozniak has not exactly left behind a trail of high-profile technological successes. He has founded only one other company—the ill-fated CL9, which made a universal remote control and folded after a few years of operation. But both Wozniak and his financial backers believe in his ability to pare a design down to the essentials—a talent that they believe will bring him success with Wheels of Zeus.

The real challenge may be establishing where wOzNet fits in the marketplace. The Wi-Fi market, which is perhaps the closest analogue to what Wozniak wants to build, generated about $2.5 billion in revenues last year—two-thirds of that from consumer applications such as home networking. Wozniak's investors believe he can distinguish his network from Wi-Fi by showing that it is uniquely tailored to short-distance GPS uses and is thus superior for the tracking services he envisions.

"I really liked the idea of a consumer technology play that is low bandwidth, with GPS," says Greg Galanos, executive managing director of Mobius Venture Capital, which invested $5.5 million in Wheels of Zeus in two venture rounds. (The startup has also received financing from Palo Alto Ventures and Draper Fisher Jurvetson.) "By targeting consumers first, it allows us to apply maximum pressure in terms of cost reduction in design—and it allows Steve to play to his strengths as an inventor."

Adds Tim Bajarin, president of the market research firm Creative Strategies, "There's no question that there's a legitimate application for it. With all the fear of child kidnappings out there, he's playing directly to a very human need."

That works for Woz.

Michael A. Hiltzik, a *Technology Review* contributing writer, is a Pulitzer Prize–winning reporter and columnist for the *Los Angeles Times*.

KURZWEIL'S RULES OF INVENTION

HE CREATED THE FIRST READING MACHINE FOR THE BLIND, THE FIRST COMMERCIALLY AVAILABLE LARGE-VOCABULARY SPEECH RECOGNITION SOFTWARE, AND A HOST OF OTHER TECHNOLOGIES. **RAY KURZWEIL** SAYS THINGS ARE CHANGING FAST FOR INVENTORS AND OFFERS HIS ADVICE ON HOW TO KEEP UP.

ILLUSTRATION BY ISTVAN BANYAI

I AM OFTEN ASKED my advice on how to succeed as an inventor. More than 30 years of experience have given me a few insights. To wit: invention is a lot like surfing; you have to catch the wave at the right time. This is why I have become an ardent student of technology trends. I now have a research staff that gathers data on a broad variety of technologies, and I develop mathematical models of how technology in different areas evolves. These models show that the pace of innovation itself is doubling every decade.

As we approach the steep part of technology's exponential growth, timing becomes ever more crucial in successfully developing and introducing an invention. You need to aim your invention at the world of the future, not the world that exists when your research project is launched. Inevitably, the world will be a different place when you seek to introduce your innovation. Everything changes—market needs, competition, channels of distribution, development tools, and enabling technologies.

To time an invention properly, you need to consider its entire life cycle. We can identify seven stages in the evolution of a technology: precursor, invention, development, maturity, false pretenders, obsolescence, and antiquity. An invention will thrive, becoming a successful product, only if the crucial phases—precursor, invention, development, and maturity—are attended to.

THE LIFE CYCLE OF AN INVENTION

In the precursor stage, the enabling factors for the new technology are in place; visionaries may even describe its operation or its goals. But the invention has yet to become a reality. Leonardo da Vinci, for example, described flying machines, but we don't consider him to be the inventor of the airplane.

Our society especially celebrates invention, but this stage exists only in the context of those before and after. Inventors need to bridge science and practical problem-solving skills. They clearly need determination; Edison, for instance, went through thousands of materials before settling on a satisfactory light bulb filament. As I mentioned, they need a sense of timing. They also need a mea-


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sure of salesmanship to attract the necessary resources, including investment and coworkers—not to mention customers.

The third stage is development. Often an invention enters the world as an ungainly and impractical device. It would be hard to develop an effective business model around the Wright brothers' airplane. Further refinements had to take place before we really entered the age of aviation.

Development is followed by maturity, which constitutes the bulk of a technology's life span. The technology has now become an integral part of everyday life, and it appears that it will never be replaced. Invariably, there are assaults on the now established technology, which form the fifth stage, that of false pretenders. Here a new, potentially disruptive technology claims to be in a position to replace the mature technology. Although better in certain ways, the new technology is invariably found to be missing salient and critical features of the established invention. The failure of the upstart only strengthens the conviction of technology conservatives that the old order will indeed hold indefinitely.

AS THE PACE OF INNOVATION QUICKENS, DEVELOPING AND LAUNCHING ANY NEW INVENTION DEPENDS URGENTLY ON TIMING.

Over time, however, new inventors master the absent qualities of the upstart, pushing the older technology into obsolescence, which constitutes about 5 to 10 percent of its life cycle. The final resting ground for a technology is antiquity. Consider today the horse and buggy, the manual typewriter, and soon, the music CD.

I have personally been involved in inventing an upstart technology to replace a venerable mature one: the piano. The precursor of the piano was the harpsichord. Musicians were dissatisfied, however, that the harpsichord couldn't vary the intensity of its sound; so Bartolomeo Cristofori invented one that could. He called it "gravicembalo col piano e forte" (harpsichord with soft and loud), or "piano" for short. It was not initially popular, but refinements ultimately made the piano the keyboard instrument of choice throughout the 19th and 20th centuries.

The false pretender was the electric piano of the early 1980s. It had many advantages: no need for tuning, a panoply of sounds, and automated accompaniment, among others. But it was missing one crucial feature: a convincing piano sound.

With advanced signal processing and insights from pattern recognition, this deficit was overcome. Today, the sound quality of electronic pianos surpasses that of the upright piano, which used to constitute the bulk of the market for acoustic pianos. Electronic instruments now come close to dominating the market for pianos, and the sale of acoustic pianos continues to decline.

THREE STEPS TO SUCCESSFUL INVENTION

Trying to predict the life cycle of your invention, as well as those of the technologies you may be displacing, is the first step to success. But fostering the key stages in the development of a new technology requires attention to detail. My experiences have led me to a number of observations on ways to facilitate the process.

One insight I've gained is that most modern technologies are interdisciplinary. For example, speech recognition, another area I've worked in, involves speech science, acoustics, psychoacoustics, signal processing, linguistics, and pattern recognition. A major challenge to interdisciplinary technology development is that different disciplines use different terms for the same concept. Norbert Wiener commented on this in his seminal book *Cybernetics*, written in 1948: "There are fields of scientific work…which have been explored from the different sides of pure mathematics, statistics, electrical engineering, and neurophysiology…in which every single notion receives a separate and different name from each group, and in which important work has been triplicated or quadruplicated, while still other important work is delayed by the unavailability in one field of results that may have already become classical in the next field."

At my companies we've solved this problem by creating our own terminology and thus, in essence, new interdisciplinary fields. The goal is to try to eliminate the tendency for everyone to describe the same thing differently and find one term to agree on. (This also has advantages in keeping our work secret: anyone overhearing our discussions has no idea what we are talking about!) We teach all the requisite disciplines to every member of the team. And to foster cross-fertilization and new ways of approaching problems, we'll assign, for example, an acoustics problem to the pattern recognition experts, and vice versa.

This brings up another critical consideration: the importance of creating devoted and passionate teams. One way to accomplish this is to adopt a goal that has the potential to inspire. I've tried to do this in my own career by selecting projects that contribute to my own social and cultural goals. And in assembling a team, I consider each member's personality and team-building skills as important as his or her technical skills. Most importantly, I try to include the intended users of a technology as key members of the team. For example, when I was developing a reading machine for the blind in the 1970s, I recruited blind scientists and engineers from the National Federation of the Blind, and when working on music synthesis in the 1980s, I required that all of the engineers be musicians. Invariably, the users of a technology are sensitive to subtle issues that nonusers fail to appreciate.

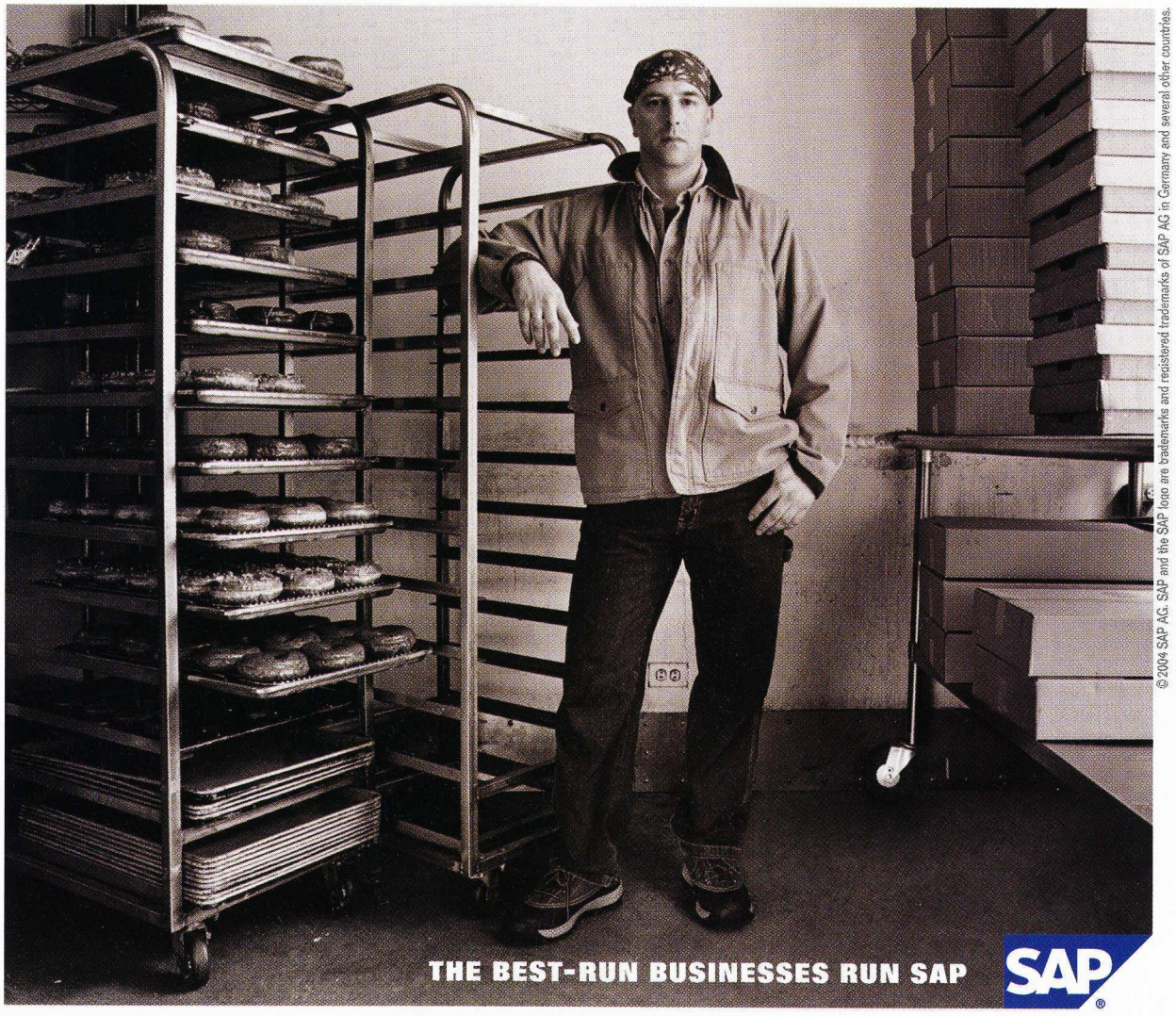
Based on these insights, I offer a three-step program for beginning the invention process, good for innovators from the lone inventor to the large corporate team. Step one is to write the advertising brochure. This can be a real challenge. It compels you to list the features, the benefits, and the beneficiaries. You will find this impossible to accomplish if your ideas are not well formed.

Step two: use this brochure to recruit the intended users. If these beneficiaries don't immediately get excited about your concept, then you are probably headed down the primrose path. Invite them to participate in creating the invention. After all, if they want it so badly, let them help you invent it.

Finally, engage in some fantasy. Sit down, close your eyes, and imagine that you're giving a speech some years from now explaining how you solved the challenging problems underlying your new invention. What would you be saying? What would you have to be saying? Then work backwards from there. TR

Ray Kurzweil has founded nine businesses based on his inventions and is a member of the National Inventors Hall of Fame.

COMPANIES THAT THOUGHT THEY COULDN'T AFFORD SAP RUN SAP.



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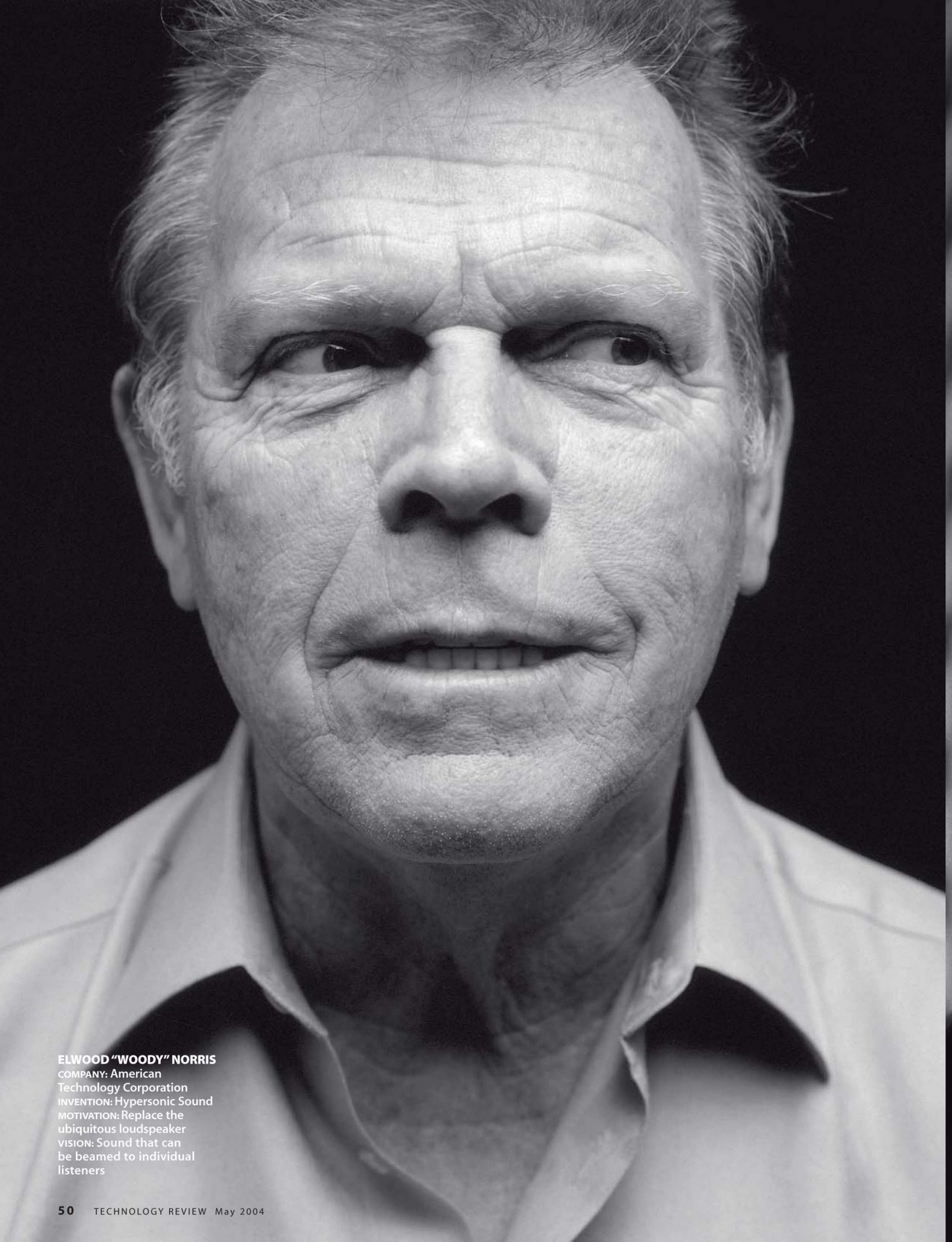


ELWOOD "WOODY" NORRIS
COMPANY: American Technology Corporation
INVENTION: Hypersonic Sound
MOTIVATION: Replace the ubiquitous loudspeaker
VISION: Sound that can be beamed to individual listeners

F. JOSEPH POMPEI
COMPANY: Holosonic Research Labs
INVENTION: Audio Spotlight
MOTIVATION: Replace the ubiquitous loudspeaker
VISION: Sound that can be beamed to individual listeners

THE SOUND WAR

Two very different inventors are locked in a head-to-head battle to tame sound. At stake are billion-dollar markets and lasting fame as the one who redefined how we all think about audio. BY EVAN I. SCHWARTZ

PHOTOGRAPHS BY BRYCE DUFFY AND ALLAN PENN

HISTORY IS REPLETE with rival inventors battling one another to bring breakthrough creations to market: Howe and Singer over the sewing machine, Bell and Gray over the telephone, Edison and Swan over the light bulb. In many cases, the winner went on to become a household name and captain of industry, while the loser was essentially forgotten.

Now, in that same tradition, two inventors are each staking claim to a new audio technology that corporate customers say will have a huge market within the next five years. Known as directional sound, it uses an ultrasound emitter to shoot a laserlike beam of audible sound so focused that only people inside a narrow path can hear it. "It's phenomenal," says Simon Beesley, an audio marketing manager for Sony's European business division. So far Sony has sold just a handful of directional-sound systems for specialty installations in stores and other locations, but ultimately, says Beesley, "Without question, this is going to be a billion-dollar-plus product."

But who will claim that billion-dollar prize? Elwood "Woody" Norris, of Poway, CA-based American Technology Corporation (ATC), and F. Joseph Pompei, of Watertown, MA's Holosonic Research Labs, have harnessed the same scientific principle to create competing directional-sound systems, and each insists his version will transform acoustics. Norris and Pompei both envision a family of four sitting in a car enjoying four different musical selections or radio broadcasts at once—with no headphones. They also see street-level billboards or displays in retail locations that speak only to one passing consumer at a time, or a crowded trade show in which the cacophony of thousands of product demonstrations is replaced by thousands of focused beams of sound confined to their own exhibits. Rather than using a megaphone, a police officer could control crowds by directing his or her voice only at a person creating a disturbance. The ultimate goal, say both inventors, is to replace a large number of the millions of loudspeakers sold each year for home entertainment and personal-computer systems with directional-sound devices.

They may share a vision, but these dueling inventors could hardly be more different. Woody Norris is a 65-year-old West Coast maverick with no college degree who got most of his formal education during a stint as a radar technician in the U.S. Air Force more than 40 years ago. The holder of a once valuable but long-expired patent on diagnostic ultrasound, the self-taught inventor has made a personal fortune that he estimates is in the tens of millions of dollars by inventing audio devices, including a hearing-aid-sized FM radio, a line of flash-memory voice recorders and car audio systems, and several models of cellphone headsets. He has been at work on what he calls "hypersonic sound" for much of the past decade and claims to have invested $40 million in its development. "He has an intuitive understanding of physics and electronics," says Curt Edgar, senior manager for advanced technology at DaimlerChrysler, who has met with Norris for demonstrations. "He's also got incredible persistence."

In sharp contrast, Joe Pompei is a 30-year-old East Coast entrepreneur with impressive educational credentials but little track record as an inventor: his Audio Spotlight system is his first major invention. In high school and during breaks from college, while working part time for Bose, the Framingham, MA, loudspeaker manufacturer, Pompei took note of the limitations of traditional speakers. But, he says, executives at Bose "were not interested in hearing about the future of sound from a 20-year-old." After receiving his electrical engineering degree from Rensselaer Polytechnic Institute, he went on to get his master's in psychoacoustics at Northwestern University. He says it was there, in the mid-1990s, that he got the idea for using silent ultrasound as a way of producing audible sound. "I was considered a mad scientist," Pompei recalls.

He first demonstrated the basic principle at the MIT Media Laboratory. While completing his PhD at MIT in 2002, Pompei launched Holosonic, bootstrapping the company with just a few thousand dollars of his own research stipend money. Pompei's system "really does behave like a spotlight," says David Rabkin, vice president of technology at Boston's Museum of Science, which uses the system in an exhibit. "You point the beam at one person and light them up with sound. But once you step outside the beam, the sound drops off quickly."

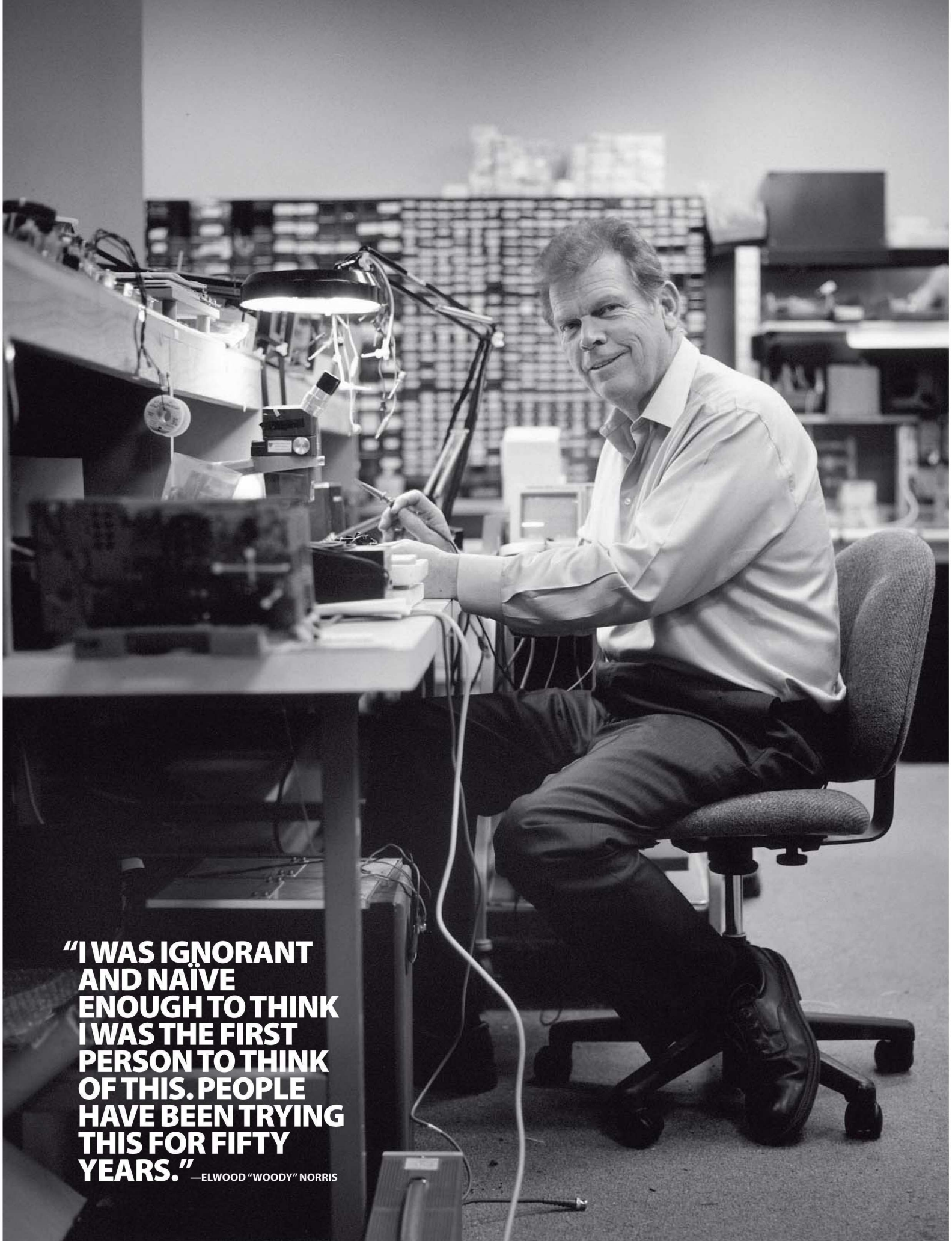
The technologies and the visions of the inventors are strikingly similar. So it's likely that the differences in their personalities, backgrounds, and business tactics will be critical factors in deciding who is the first to overcome the roadblocks—including high costs, lack of mass-production standards, and performance kinks—that stand between them and the lucrative markets they both envision. Which one of them prevails, if either, will speak volumes about the relative value of education and experience, youth and wisdom—and perhaps luck and timing—in ensuring an inventor's place in history.

HEARING THINGS

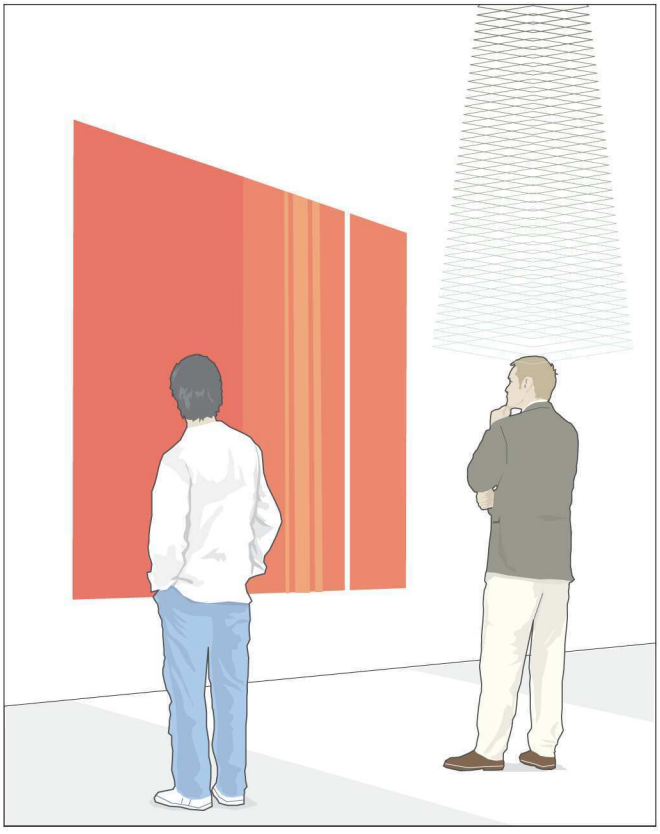
One thing Pompei and Norris have in common is this: each quickly learned that in chasing directional sound he was heading down a path others had trod before. Norris says he first got the idea for what has become his Hypersonic Sound system in the late 1970s. He had recently raised money by selling stock in one of his startups and, flush with cash, was eagerly looking for his next big thing. "I was ignorant and naïve enough to think I was the first person to think of this," he says. But as he researched old patents and publications, "names came out of the wall. People have been trying this for fifty years." Pompei's own research revealed that major Japanese corporations had looked into the concept in the early 1980s but abandoned their quest, suspecting that the technique would produce distorted sound or require too much power to be of any use.

Both Norris and Pompei believe they have solved most of the problems that stymied their predecessors. Each of their systems contains a signal processor, an amplifier, and a platelike device that shoots out beams of ultrasound. At his suburban San Diego laboratory, Norris plugs his Hypersonic Sound emitter into an ordinary portable CD player for a demonstration out-

PREVIOUS SPREAD AND OPPOSITE: BRYCE DUFFY (NORRIS); ALLAN PENN (POMPEI)



"I WAS IGNORANT AND NAÏVE ENOUGH TO THINK I WAS THE FIRST PERSON TO THINK OF THIS. PEOPLE HAVE BEEN TRYING THIS FOR FIFTY YEARS." —ELWOOD "WOODY" NORRIS



Sound and silence: Directional-sound systems could create discrete zones of sound in otherwise silent locations. Here, one museumgoer learns about a painting by listening to a beamed-in commentary while another chooses quiet contemplation instead.

side in the parking lot. When he points the device at a visitor standing about 20 meters away, the visitor is able to clearly hear sounds ranging from a waterfall to jazz music. But when Norris points the emitter to the left or right or up to the sky, the visitor hears no sound at all. Inside the lab's conference room, Norris directs the emitter at walls, bouncing the sound beams so that they seem to be coming from spots on the wall, rather than from the device itself.

It's easy to see why directional sound is cool, but understanding how it works is far tougher. Traditional speakers generate audible sound waves that spread out in all directions like ripples from a pebble tossed in a pond. Norris's and Pompei's devices instead generate narrow, laserlike beams of ultrasound waves, which have a frequency above 20,000 hertz, the upper limit of what the human ear can detect. Both audible sound waves from traditional speakers and ultrasound waves from a directional-sound system distort when they travel through the air; in a traditional sound system, the distortion slightly degrades the sound a listener ultimately hears. But in a directional-sound system, the distortion is actually the mechanism that generates the audible sound, breaking the ultrasound waves into lower-frequency, audible sound waves along a straight, narrow path.

PUMPING UP THE VOLUME

The paths of the two inventors, on the other hand, are converging on a marketplace battlefield where corporate customers will be won and lost. The clash is already fierce. Pompei, for instance, says that his is the only directional-sound system that has been built into a vehicle from a major manufacturer.

In fact, three years ago, when the Audio Spotlight was part of a project at the MIT Media Lab, research sponsor Daimler-Chrysler did indeed incorporate a prototype into a concept car, with transducers located above each of the four seats in the cabin. "Functionally, it worked," says Daimler's Edgar. But there was one main glitch: the beams would bounce off of the seats and other surfaces, deflecting sound between the zones. Because of that drawback, and the high cost of the system, the automaker didn't pursue it further. Instead, a year ago, Edgar got in touch with Norris. "ATC has made more strides, in terms of cost and manufacturing and performance," says Edgar. "They are a couple generations beyond where Holosonic was." Still, Norris's system has yet to be built into a vehicle, and there are no immediate plans at Daimler to do so.

Norris admits that he is working on improving the performance of his Hypersonic Sound system. One issue is the technology's current inability to produce low bass tones, a shortcoming that Pompei's system shares. But Norris says that Sony is already rolling out the product in Europe. Sony's Beesley confirms that the company has to date distributed hundreds of Hypersonic Sound systems, which it integrates with its plasma video screens for specialty applications. He says that department stores, banks, and museum exhibitors are using the technology to beam sound at customers and visitors in particular areas. "It has huge potential," Beesley says. The main limitation of the system, he adds, is its price. "It's pretty much hand-built right now," he says, at a cost of about $1,000 per unit. "We're looking at various industrial designs to make it cheaper and easier to produce." The goal is a price point of less than $100 per installation. Daimler's Edgar says a similar price point is essential to making directional-sound technology competitive with traditional car-stereo speakers.

At $1,000 to $2,000 per system, Pompei's Audio Spotlight suffers from the same high-cost, low-production-quantity syndrome. Early customers such as Steelcase, which is testing it for office environments, and Cisco, which has installed it in corporate lobbies, have only purchased a few units each.

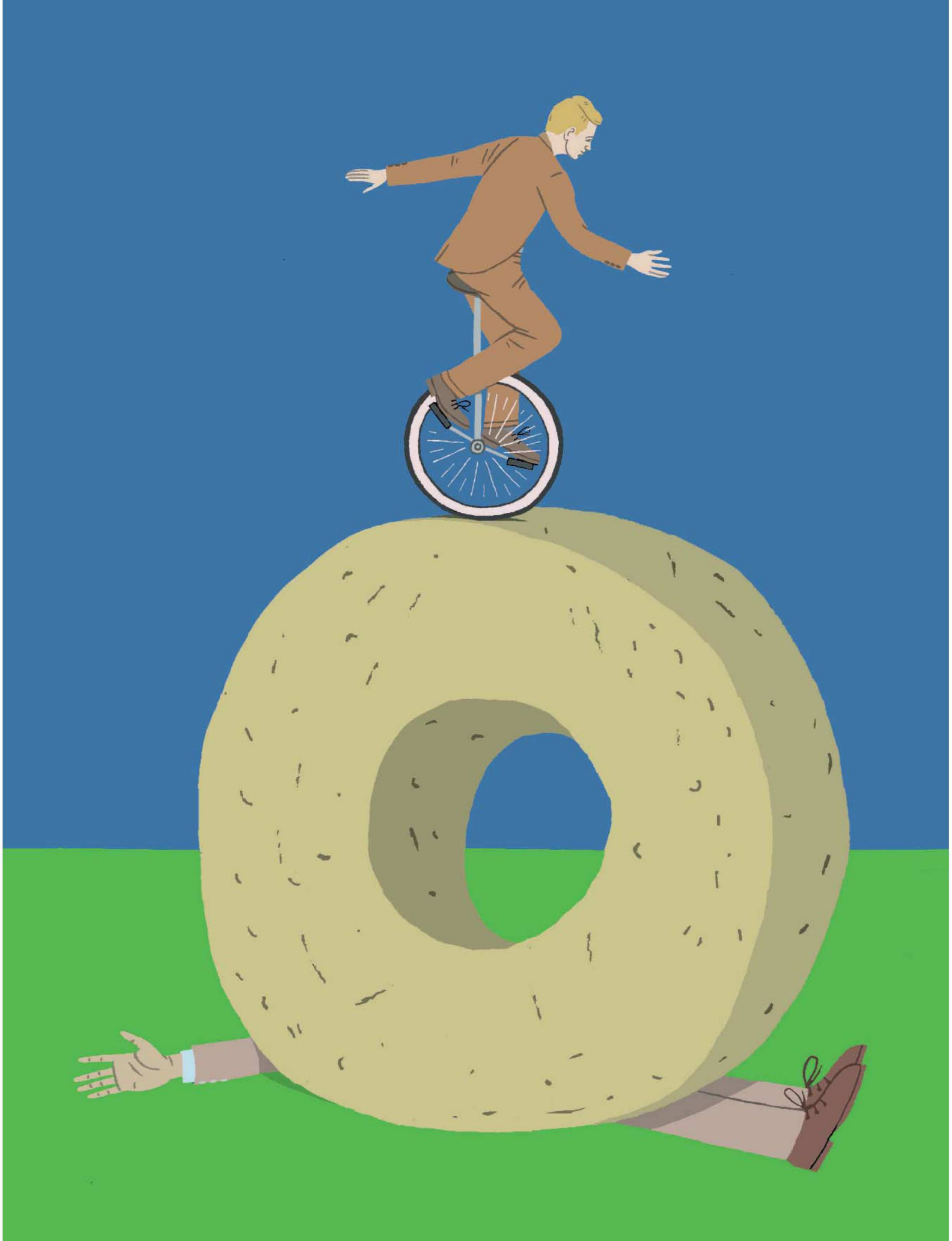
As ATC and Holosonic race to transform their systems from high-end curiosities to household staples, Norris says he is relying on his patents to protect his intellectual property in the marketplace. On that front, he appears to have the edge on Pompei. Norris has about 20 issued patents covering various aspects of directional-sound technology, and he says that 20 additional ones are pending. Pompei says he has about a dozen patents pending, including two key ones, but only one that has been issued so far.

Given the similarity in the technologies and visions of Pompei and Norris, the shouting match is likely to get louder. The one thing the two inventors can agree on is that directional sound has real long-term opportunities, especially when it comes to displacing the ubiquitous loudspeaker, invented more than 80 years ago. Even the best loudspeakers, they agree, are subject to distortion, and their omnidirectional sound is annoying to people in the vicinity who don't wish to listen. What remains to be seen is which, if either, of these two inventors will become the Alexander Graham Bell of directional sound, and which will become the Elisha Gray.

Why big companies can't invent

Technology analyst and leading venture capitalist **Howard Anderson** asks, Is the vaunted corporate research-and-development laboratory obsolete as a source of meaningful invention and innovation?

Illustration by Scott Menchin



IT'S OFTEN SAID that Thomas Edison's finest invention wasn't the light bulb or the record player; it was the concept of an ongoing industrial innovation and development process. Corporations from Edison's own General Electric to Ma Bell, Corning, and Kodak took his idea and ran with it, setting the stage for the modern R&D lab.

While independent inventors were once the main source of patents, since the 1930s, corporate labs have been the dominant wellspring of invention. For decades, these organizations drove corporate growth, and they developed many of the fundamental inventions that run modern life: Bell Labs and the transistor, RCA and color television, GE and MRI technology. In the process, R&D has become the ultimate corporate sacred cow. Until recently, corporate gospel has been that sustained high investment in research will lead to a boatload of insanely great products that will carry a company to a new level, driving growth in profits and staking out vibrant emerging markets. But it's time to ask some hard questions: Does corporate research and development really work? And if it does, why are so many prestigious and supposedly well-run firms continually blindsided by competitors?

The answer is, at best it's not working well, and perhaps it just doesn't work at all anymore. Corporations need to take a closer look at their devotion to internal research. We're entering a new era of invention, and big companies must adapt and begin practicing invention triage—keeping only what works, fixing what can be fixed, and throwing out the rest.

IBM, for instance, employs 3,000 full-time researchers yet has rarely been a market innovator. It spent $5.1 billion on R&D last year—6 percent of its revenue and $16,000 per employee. Yes, Big Blue does make $1 billion each year licensing the technology these inventors create to other firms. But look at the companies that are whopping IBM: Cisco, EMC, Oracle, and Sun, among others. These companies spend far less on research than IBM. Oracle, which long dominated the relational-database market, took the idea right out of a paper by an IBM researcher! In external computer storage, EMC, a relative newcomer, has 19 percent of today's $13 billion market to IBM's 15 percent. Fifteen years ago IBM had 80 percent. And IBM is not alone in its R&D failures.

Look at Apple. It invented the personal-computer industry with the Apple II in 1977, popularized the graphical user interface, and pioneered intuitive software—and became the first personal-computer company to reach $1 billion in annual sales. But once Apple made it big, it stalled. Today the company has only 2 percent of the $180 billion personal-computer market. Apple spends $471 million a year on R&D, a full 7.6 percent of its revenue. I defy you to name me another company so innovative with so little to show for it.

How about Xerox? Okay, you win. Xerox makes Apple look like a stellar success story. Picture a corporate meeting back in 1970. Xerox is getting filthy rich. It wouldn't even sell you a copier: you rented the damn things and paid for every copy you made. Research leaders convinced management that it had to plow back millions into research—without offering any guarantee that anything worthwhile would come of it. They hired the smartest people and built Xerox Palo Alto Research Center. PARC researchers invented the Ethernet, windowed computer applications, screen icons, and laser printers. Of the 10 most important developments in computing, Xerox PARC birthed at least half of them.

And how did Xerox management handle this windfall? They blew it. Choked. Perhaps the biggest screw-up in technology history. Almost every other company in Silicon Valley benefited from PARC's innovations, but the only one Xerox managed to cash in on is the laser printer. And though printers now form a serious chunk of the company's business, even in that space, Hewlett-Packard is the clear winner. Xerox still spends almost $900 million in R&D annually, almost 6 percent of its revenue. And do they have any knock-your-socks-off products to show for it? Nope. Can you think of a worse-run company over the last 20 years than Xerox—a company that did everything it was supposed to do to build internal innovation and has still failed spectacularly?

So what should the criteria be for seeing if R&D dollars are well spent? Number of patents? Patents per research dollar? Market share? Or market share of technology developed in-house? It's kind of like a major-league baseball team seeing what percentage of its starting lineups has come from its farm teams. One winning metric: revenue growth of 15 percent to 20 percent a year, driven by internally developed products.

But few companies can claim such success. We have been evolving over the last few decades toward an age in which corporate R&D just doesn't work. There are three reasons why.

Clayton Christensen delineated the first brilliantly in *The Innovator's Dilemma*. Any new technology threatens to cut the profit margins of the bigfoot products that carry the market leader. Why would RCA or GE push solid-state technology when the profits from vacuum tubes were so high? Why would Kodak push for digital cameras when its real money was made in film? All eventually entered these markets, of course, but late, and only when change was inevitable. Major corporations much prefer "just-in-time" innovation—innovation that peaks just as older products are on the back half of their life cycle. But innovation does not choreograph so simply; it comes in fits and starts, defeats mixed with occasional breakthroughs.

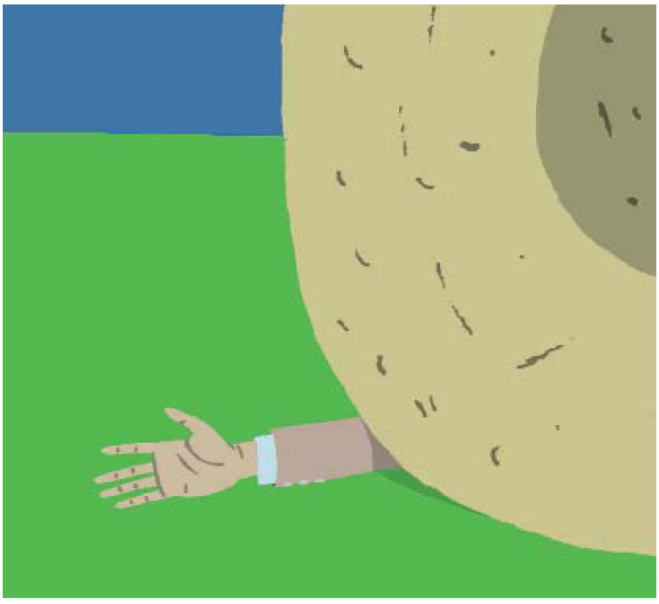
For decades, R&D labs drove the fundamental inventions of still works, why are so many

The second reason: us venture capitalists. We have about $100 billion just sitting on the sidelines. We often will pick out the best research teams and set them up as independent companies—something a big firm is loath to do. And we can make company founders rich beyond belief (at least that's what we tell them). We will steal the best researchers—those with a sense of urgency and a track record—and beat the big guns to market. That is our job, and we do it well.

The third reason we're heading for a new model of corporate invention is execution. Every company likes to innovate; very few companies want to execute the plan to take a development and productize it. That's hard work. Part of the problem is the internal barriers that corporations put up, but that isn't the real

key. Show me the internal compensation system for a company's general managers, and I will show you why its execution is just plain awful. Companies reward managers for making their numbers, not for building new businesses. Who wants to risk her bonus for an upstart technology that threatens the cash cows?

Corporate R&D spends 80 percent of its time and talent on "product improvements" and 20 percent on really new stuff. Last year my friend Kenan Sahin, a former vice president of software technology at Lucent Technologies' Bell Labs, addressed this issue a different way *(see "Our Innovation Backlog," TR December 2003/January 2004)*. Kenan bemoaned the shrinking amount of



corporate growth and developed modern life. But if corporate R&D firms blindsided by competitors?

research—and more importantly, commercialization of research—done by our largest companies and suggested that we reverse this trend. Let's look at it another way: since corporate R&D departments do so little with all the money they get now, shouldn't corporations spend less on research?

CEOs ride a perpetual roller coaster. Outsource R&D or bring it back in-house? Invest in venture capital funds to get a "window on technology" or suck up to the major research universities? Obtain technology by acquiring upstarts or make strategic investments in younger firms? Sign a codevelopment contract or build a distribution agreement? All are efforts to make this damn thing called R&D work. When did financial engineering replace real engineering?

One way to look at the research and development universe is to divide the world into two groups: attackers and defenders. The defenders are all the companies you know—AT&T, IBM, Wal-Mart. Once these giants were young and aggressive attackers—when the defenders were Western Union, National Cash Register, and Woolworth. But now they are the kings of the mountain. The defenders have markets and customers and capital and hired expertise. They believe in an orderly R&D process, and they're generally driven by financial concerns. In any market, every defender must protect its best products and customers and also attack the adjacent markets. It can either take its existing products and retool them for new markets or take its existing customers and find other products or services to sell to them. Or both.

What innovators from the defender side want to do is to keep the status quo—although they firmly deny that. But if they can keep their margins and their market share relatively steady, the results are fine. The stock will appreciate 10 percent or 15 percent per year, and senior management's stock options will make them wealthy by retirement time. Yes, they talk about "attacking"; they use every war and football analogy known. But when all is said and done…they want to sleep well at night.

The attackers are companies you've probably never heard of—Alkermes and A123Systems and Kubi Software. [Anderson's YankeeTek Ventures has invested in A123Systems. Ed.] The best way to describe them is as true samurai, aggressive warriors. The attackers have no market share, no customers, and sometimes no clue. What they do have is an open field. Innovators from the attacker side want to topple the big boys and become defenders themselves—or at least to attain a version of success by selling out to defenders. And they throw all their energy into inventing new technologies to realize those goals.

The defenders, meanwhile, see these new technologies and go through a few predictable phases—not unlike those popularly associated with grieving.

Denial. "This new technology won't work (or is dangerous or doesn't conform to standards), and our customers don't want it!"

Anger. "How dare our good customers (friends, fellow members of the club) give even a little of their business to these interlopers! Don't they appreciate the great service and support we've been giving them?"

Reluctant acceptance. "Okay, there is some merit to the technology. So let's make it available—but only to those customers who want it and whom we might lose anyway. And let's tell them why they really don't want it, even though they think they do—and keep trying to sell as much of the older, more profitable product as possible."

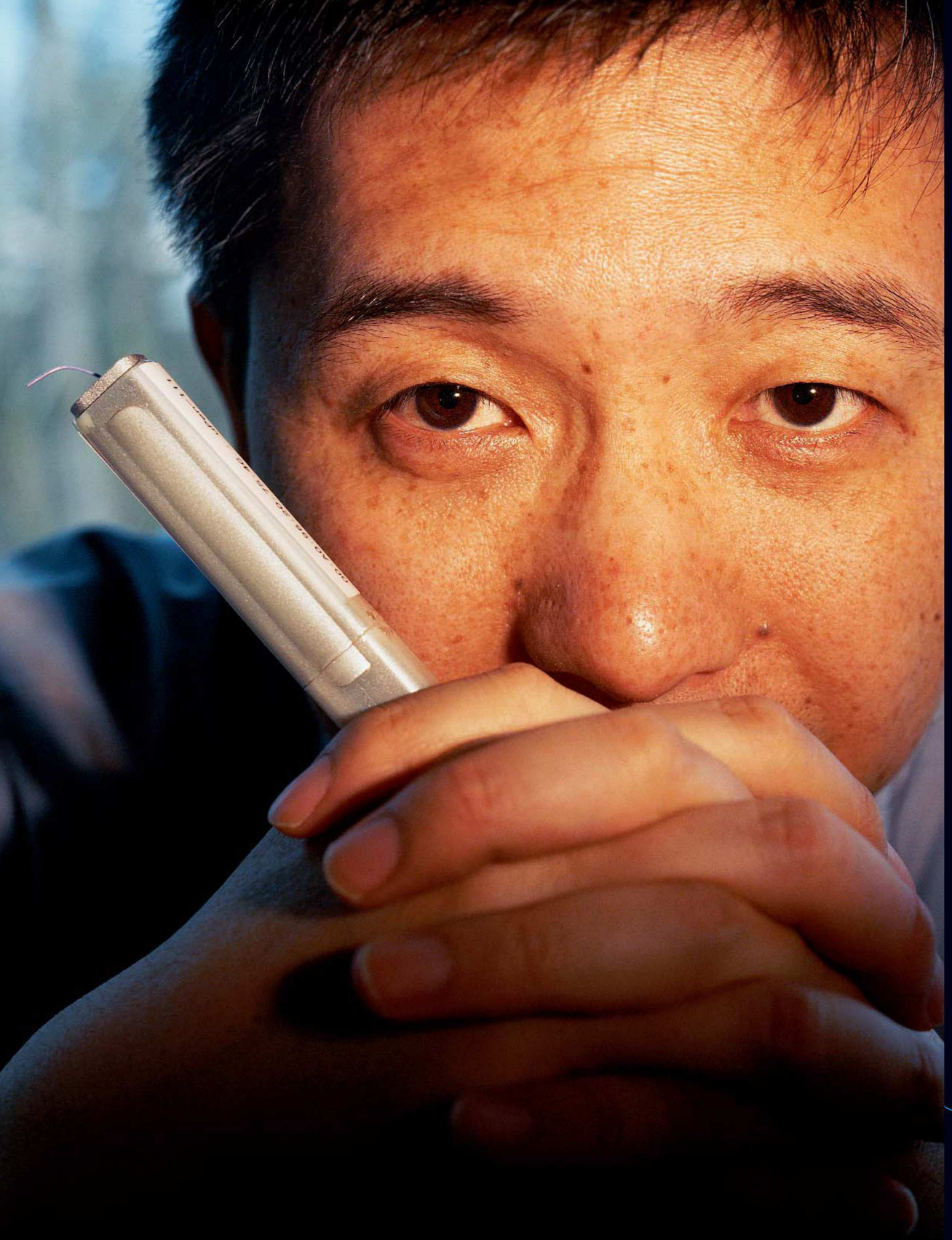
Capitulation. "Look—the market is moving away from us faster than we thought! Our own R&D is horribly late again; when they finally get the product ready it will be so hobbled as to be worthless. So let's invest in (or buy) the damn competition now, before they get too big."

Which brings me back to Edison. His model is expensive and probably did the job as long as companies had virtual monopolies in their areas. But with the advent of venture capital, the model began to change. Now "the competition" is rarely a bigger company but a smaller, focused one. Companies such as Motorola and Kodak and Boeing are finding themselves whipped by upstarts with specialized technology and faster feet.

The old model of the corporate R&D lab as the engine for invention lasted 70 years. What every company needs now, regardless of size, is the single-mindedness and sense of urgency of entrepreneurial firms.

The old model is dead. Time to build a new one. TR

Howard Anderson is the founder and senior managing director of YankeeTek Ventures and the William Porter Distinguished Lecturer at MIT's Sloan School of Management.



JIAN WANG
COMPANY: Microsoft
INVENTION: Universal pen
MOTIVATION: Closing the analog-digital loop
VISION: Capturing handwriting digitally so users can edit computer files on paper

MICROSOFT'S MAGIC PEN

Jian Wang is rewriting our relationship to computers—and paper—with a pen that turns scribblings into digital data. And in the process, he has helped make Microsoft's Beijing research lab a hotbed of invention.

BY GREGORY T. HUANG PHOTOGRAPH BY BRIAN SMALE

IF JIAN WANG HAD HIS WAY, EVERYTHING WOULD BE DIGITAL.

"I hate printers—they turn digital things into analog," he jokes, wading through a sea of cubicles at Microsoft Research Asia in Beijing, China. Fortyish and lanky, the computer scientist specializes in inventing new computer interfaces to bridge the gap between analog and digital. His own interface, though, is a wide smile, which complements his denim shirt and easygoing manner.

Stopping at a desk, Wang picks up a rectangular, silvery pen about the size of a magic marker and scribbles some corrections on a paper document. But this is no ordinary pen. A few seconds later, his comments appear on a nearby computer screen—superimposed on the electronic version of the document in the exact spot where he wrote on the hard copy. Wang's pen captures handwriting and lets users make changes to digital files—on paper.

This "universal pen," as Wang calls it, could transform the way people interact with computers. Unlike gizmos that write on computer displays or special pads of paper, Wang's invention uses regular ink, works with regular paper, and lets users combine handwritten text and diagrams with digital content from reports, magazines, and Web pages. An executive on a plane trip, for instance, could mark up a paper copy of a report and later transfer the changes to the file on his or her computer automatically.

Wang's digital pen also reflects an ongoing transformation in the process of invention at some large corporate labs, a hybridization of the lone inventor and traditional corporate R&D. Wang is the pen's lead inventor, and it is his insight, daring, and creativity that have largely driven the effort to develop it. But at the same time, he could not have made such rapid progress without Microsoft's collective expertise in pattern recognition algorithms, computer vision, handwriting technologies, and text-editing software. "Personally, I'm really excited about it," says Rick Rashid, senior vice president of Microsoft Research, whose main facility is in Redmond, WA. "It's an example of a new kind of product incubation that we do,...one that brings together people with many different skills to solve a unique problem."

MICROSOFT CALLING

Himalayan stacks of papers fill Wang's office, despite his proclaimed distaste for printouts. Amidst these reminders of the analog world, the inventor describes the beginnings of the pen project. As a professor of engineering psychology at Zhejiang University in Hangzhou, China, Wang had made his name in human-computer interfaces and virtual-reality systems. Then, in 1998, at the height of his academic career, he received a cryptic e-mail from Kai-Fu Lee, a renowned researcher who was just starting up Microsoft's Beijing lab. Lee suggested they meet but was too busy to explain why. "I don't know how he got my name," laughs Wang, "and he didn't explain who he was."

Feeling adventurous, Wang went anyway. He quickly discovered that he and Lee shared the ambition to create a user interface for computers that was based on handwriting. The pen project was inspired in part by Wang's desire to enable mobile computers to handle handwritten Asian languages. But from his academic research on 3-D interfaces, he had learned that if technology isn't designed to be practical and appealing to a variety of users, it won't be widely adopted. "We wanted to make a breakthrough, not improvements," he says, adding that in Microsoft he had found a perfect partner. "I realized this is the place to be if you want your invention to be used by millions of people instead of just a couple." With that motivation, Wang left Zhejiang University and joined the Beijing lab in the fall of 1999.

Immediately, Wang, Lee, and a core group of researchers began daily brainstorming sessions to iron out the project's goals—sessions that eventually included their top boss. "When we talked with Bill [Gates] about this technology," says Wang, "we realized we are inventing a new kind of document, not just a pen." The key idea, which fits with Microsoft's business of making office computers more useful, was that a document could be kept digital even when printed—with the right kind of pen interface and software.

It took the better part of four years to make it work. Not only did Microsoft stick with Wang, but it also allowed him to build a team of about 20 researchers, giving him access to the skills in programming and hardware he needed to design the pen. After a few false starts—including a cumbersome version that inferred what the user was writing from the pen's movements—Wang's team took advantage of advances in computer vision algorithms and based the pen's sensing on a simple digital camera.

The researchers' first challenge was finding a way to determine the pen's position on the page. Their solution involves special software that puts a barely visible background pattern, like a watermark, on standard copy paper as a document is printed *(see "Putting Pen to...Computer," p. 63)*. That enables the computer to figure out not only exactly where the pen is relative to the document but also which document is being modified, because each page has a unique code. A pressure sensor in the pen triggers a tiny embedded camera, which snaps pictures of the user's writing. The images are stored in the pen on a memory chip like those found in digital cameras; when brought within a few meters of a PC or laptop that has the proper software installed, the pen transmits the images wirelessly using a Bluetooth connection.

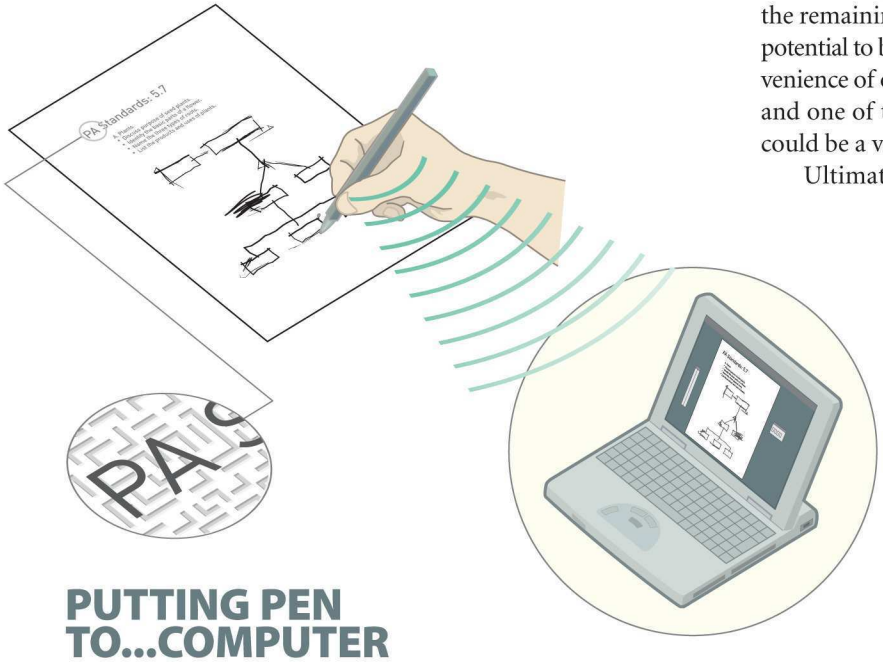
Interpreting those images and incorporating them into digital files turned out to be a tougher problem. The trick, Wang explains, is getting the computer to recognize different types of writing and drawings—to know what's a box, what's a sentence, and what's a doodle—just from a series of photos. First, computer vision algorithms classify sequences of marks as words, diagrams, or shapes, all of which can be manipulated. Then character recognition software—the subject of years of intensive research at Microsoft and elsewhere—makes sense of the handwritten text. On the computer screen, the user's marks show up as handwriting embedded in the document. Software tools can then convert the writing into typed text and rendered graphics; with these tools, the user can manipulate, say, boxes and text from a hand-drawn flow chart.

In addition to enabling users to import and manipulate handwritten text, tables, and charts, says Wang, the pen will allow multiple collaborators to make comments on separate printouts of a document; the computer could then integrate them all into the same file. The end result, says Wang, will be an interface like a portable scanner—but one smart enough to "understand" the images it captures and to fulfill its inventor's dream of turning mounds of "analog" paper back into digital files.

PERVASIVE PENS

Away from the lab, over a meal of Shanghai-style meatball soup and steamed fish, Wang explains how the lab's culture promotes invention. Besides sharing a "work hard, eat hard" mentality, he says, the lab's members—and leaders—are experienced researchers who understand that breakthroughs take time. "You don't always have to prove yourself in a month, or even a year," says Wang. So researchers have the flexibility to try a variety of approaches—important for ambitious projects like reinventing the pen.

Microsoft Research Asia is a large corporate lab, employing 150 full-time researchers, but it has surprisingly little bureaucracy, Wang says. No special approval procedures. No heavy-handed mandates from above. The company attempts to nurture invention by giving its engineers the freedom to explore interesting avenues of long-term research, while staying focused on near-term results by setting milestones and conducting project reviews a few times a year. That makes it "more like an academic-style setting," says Wang. "We publish papers, go to conferences, and host many visiting professors. It's an open environment."



PUTTING PEN TO...COMPUTER

THE PEN contains a digital camera, a pressure sensor, a Bluetooth radio, and a memory chip. As the user writes on paper, the camera snaps tiny images of the ink.

THE PAPER has a background pattern, like a watermark, that is printed with the document. The computer uses this code to figure out exactly where the ink is on the page.

THE COMPUTER receives the sequence of images wirelessly and reconstructs the handwriting in the right place in the digital document file. With special editing software, the user can then manipulate and format the handwriting.

Observers say that this openness is essential to the lab's productivity, especially in a country with a limited history of corporate research. "They've been a success because of their ties to academia," says Shiqiang Yang, executive vice chair of the Department of Computer Science and Technology at Tsinghua University, one of Beijing's leading engineering schools. The free exchange of ideas with students and professors has strengthened the lab's standing in the academic community—and that helps it recruit some of China's top students and computer scientists.

The close ties are paying off: more than 70 technologies developed at the Beijing lab have found their way into Microsoft products in areas such as video game graphics and speech recognition for dictation. As for Wang's digital pen, it could open up whole new markets for Microsoft. Although commercialization is still a few years away, Wang's team is in discussions with the company's product development groups in Redmond. Specific product plans have not been made yet, says Rashid, "but it generates a lot of exciting ideas about what might be possible."

In fact, technologies developed by Wang's group in the course of the pen project are already paying dividends to the company. Software that can recognize and manipulate handwriting on a screen is a feature of the Tablet PC operating system Microsoft released in 2002. The Asian market could be the first point of entry for interfaces like the digital pen because of the demand for software to recognize and edit Asian-language characters, the sheer number of which makes them tedious to input using keyboards.

With any new invention, there are numerous challenges in transforming an exciting prototype into an actual product; but here, Wang's training in psychology and human factors should serve him well. The pen and its software need to be made easier to use, he says; customers won't tolerate added complexity. With the remaining kinks worked out, however, the invention has the potential to become ubiquitous, because of the familiarity and convenience of ordinary pens. "The pen is so pervasive, so expressive, and one of the best inventions," Wang says. "So I think the pen could be a very good computing device for the future."

Ultimately, says Wang, everything on your desk—books, journals, printouts—will have a digital connection to your computer. It's what he calls "closing the loop between analog and digital." And with increases in computing power and memory, a device like Wang's pen could become the main computer interface people use on the road. Wang envisions that users could not only enter and store data but also, with a wireless handheld computer, access information in, say, a magazine article just by underlining words that can be recognized and "looked up" on the Web.

With so much to do, though, Wang has no time to waste. He might work for one of the world's largest corporations, but he still keeps the long, nighttime hours of a lone inventor. After dinner, while most of Beijing is dark and quiet, he goes back to work, intent on penning the future of human-computer interfaces.

Gregory T. Huang is a *Technology Review* associate editor.

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YOUR SUCCESS IS OUR BUSINESS

pat-'ents '04

inside:

THE BENEFITS OF patenting inventions have not changed much since U.S. patent number one was issued in 1790 to Samuel Hopkins, who developed a process for making potash, a chemical ingredient essential to glass, soap, and gunpowder. The patent allowed Hopkins to disseminate his technology without giving it away: he sold five-year licenses for $200. Hopkins's process became the industry standard, and the United States became a leading producer of potash until the 1860s.

The trick, of course, is to pinpoint the few patents, out of the thousands issued by the U. S. Patent and Trademark Office each year, that will have the kind of impact Hopkins's innovation had in his day. But *Technology Review* is up to the challenge. In **"Five Killer Patents"** *(p. 66)*, we focus on inventions from giants IBM and Lucent and small fry Israel-based superDimension, a maker of minimally invasive medical diagnostic tools. We think these patents—which range from a safer lung biopsy technique to software for reducing the chance of fraud during telephone transactions—will profoundly influence their respective fields for years to come.

For the bigger picture, turn to *Technology Review*'s annual **Patent Scorecard** *(p. 71)*, which ranks the U.S. patent portfolios of 150 top technology companies in eight sectors, and the **Global Invention Map** *(p. 76)*, which shows at a glance the origins of all U.S. patents issued in 2003. As you thumb through both, consider that three or four years ago—when most of the 2003 patents were filed—the bottom was falling out of the technology market. With layoffs and business closings reaching epidemic proportions, it might have been fair to guess that invention would stagnate. But the data suggest otherwise. The scorecard figures for technological strength—which gives an overall assessment of a company's intellectual-property power and is the basis of our rankings—have shifted dynamically. Companies such as Delphi, Affymetrix, Intel, and Matsushita Electric show leaps in technological strength over their average scores for 1998 to 2002. It's important, of course, to consider the context for such shifts. Part of Intel's 45 percent jump, for instance, was due to its acquiring a number of smaller firms. But the company stayed the course on R&D when times were tough. That commitment to invention—shared by many others showcased in this special section—carries on a tradition begun in the United States more than 200 years ago.


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5 killer patents

They could save you from surgery, transform your telephone, and provide all the handheld computing wizardry you'll ever want. After scouring corporate and university labs around the world, *Technology Review* found five patents issued in 2003 poised to change computing, medicine, communications, and security.

ILLUSTRATIONS BY GREG MABLY

№ 6,529,499

A GOOD CALL FOR THE INTERNET

Lucent Technologies

INVENTION: Method for ensuring that voice data packets get high priority on the Internet

BENEFIT: Could give Internet telephony the same reliability and high quality as landline phone calls

IN THEORY, using the Internet to make phone calls could revolutionize telecommunications by enabling cheap links to anywhere in the world, the convenient bundling of voice messages and e-mails, and services that integrate voice and video. But in practice, service quality is still a major stumbling block to widespread implementation. An Internet call—like all other data on the Internet—is broken into packets that travel along myriad pathways where they must compete for bandwidth. The result: Internet calls can become riddled with clicks and short delays.

A patent issued to Lucent Technologies—the company's 30,000th to date—describes technology that could improve Internet telephone service, finally unlocking its full potential. Lucent's innovation is software that behaves like a traffic cop for data packets—but a traffic cop that has some clear preferences. The software receives information about bandwidth capacity and determines whether to allow packets for Internet calls onto a given network path or to direct them to a different, less congested path. The software then ensures that real-time data packets, such as voice data from conversations, are given priority.

While many other approaches to solving the Internet telephony problem simply add more routers or increase bandwidth on local networks, Lucent's method works with existing equipment, says Yung-Terng Wang, one of the inventors. Indeed, "Lucent's proposal seems to be simple enough and does the job," says Steven Low, a computer scientist at Caltech, whose group works on Internet congestion control.

The company will incorporate the technology into systems it sells to telecom companies like Qwest of Denver, CO, and Phonom of Richmond, VA. Of course, Lucent isn't the only player looking to improve Internet telephony. But given its technical background and expertise, a lot of people are listening clearly to what the company has to say. **TRACY STAEDTER**

№ 6,529,871

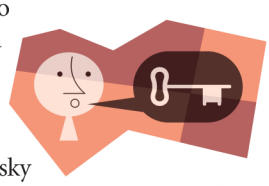
A VOICE OF APPROVAL

IBM

INVENTION: A way to verify identity using both voice authentication and personal queries

BENEFIT: Reduces the chance of fraudulent telephone transactions

DIAL UP YOUR BANK, and chances are a recorded message will request your personal identification number, and an operator will ask for your mother's maiden name or other personal information. It's hardly an infallible way to verify identity. An alternate method—automatic voice recognition—can have trouble with background noise or even the natural variability in people's voices. But by combining the two methods, IBM believes it has created a way to provide far better fraud protection than either affords alone—without sacrificing convenience.



The invention—by Dimitri Kanevsky and Stephane Maes at IBM's Watson Research Center in Yorktown Heights, NY—records a "voiceprint," or sample of a user's speech, for later comparisons. It also records the user's answers to a series of personal questions. Then, during a transaction, if both the voice and the answers match its records, it grants access. But it's not quite that simple: the technology also generates additional questions based on account information, such as, "What was the amount of your last withdrawal?" It asks questions in random order, so recordings of previous sessions can't be used to commit fraud. And it can be calibrated to ask more questions, or require a closer voice match, for a customer requesting a large transaction.

Several IBM customers are now testing early prototypes, which build on IBM's expertise in voice recognition technology. The challenge lies in getting all the variables aligned for the tightest security with the fewest delays or errors. Though there's no official date for a product launch, the system could be on the market in a few years. IBM hopes the technique will eventually become as mainstream—and secure—as today's fingerprinting, iris-scanning, and facial recognition systems, which are projected to form a combined $1.2 billion market this year, as places like airports and banks begin using them as security measures. **PATRIC HADENIUS**

№ 6,545,906

MEMORY BOOSTER

Motorola

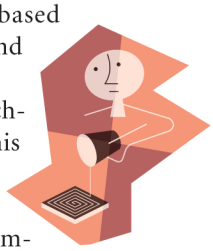
INVENTION: A technique for more accurately writing data on magnetic memory chips

BENEFIT: Makes a new kind of nonvolatile semiconductor memory commercially viable

MAGNETIC RANDOM-ACCESS MEMORY, or MRAM, has long been held out as a potential next-generation, universal memory technology. It is faster and more durable than the flash memory used in handheld devices, and unlike the dynamic random-access memory used in PCs, it doesn't lose data when its power is turned off. These attributes make MRAM attractive for everything from digital cameras to instant-on laptops.

But scientists have struggled for years to make it work. MRAM stores data in an array of small magnetic devices, or cells; electrical pulses write data by flipping the cells' magnetic orientation. The problem: flipping one cell often flips neighboring ones, too. These errors become more and more an issue as the cells become smaller and their shapes less precise. Leonid Savtchenko, a scientist with Motorola in Chandler, AZ, devised a solution—a two-step method of applying the elec-

trical pulses such that only the targeted cell is flipped. It makes MRAM reliable even when the inevitable manufacturing imperfections create irregular-shaped magnetic cells that are particularly prone to accidental flipping. The new approach, awarded a patent last year, "solves the manufacturing uniformity problem," says MRAM pioneer James Daughton, chief technical officer at Eden Prairie, MN-based NVE, which is also developing MRAM and makes sensors using similar technology.



Savtchenko didn't live to see his technology proven, but after his 2001 death his colleagues finished its development and named it in his honor. Savtchenko switching made possible the company's first commercial MRAM chips, which will reach the market later this year. While these early chips will be too expensive for consumer electronics—initial applications will include memory in military systems—Motorola is working on MRAM for wireless devices and is licensing the technology to other chip makers. The combined efforts of Motorola and its licensees mean Savtchenko's clever solution to a lingering problem won't be forgotten. **RUSS ARENSMAN**

No. 6,593,884

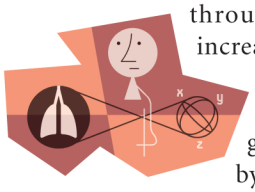
3-D TRACKING FOR LUNG SURGERY

superDimension

INVENTION: A system for visually tracking the locations of bronchoscopes used in lung biopsies

BENEFIT: Allows safer and far less invasive biopsies

EVERY YEAR, roughly three million people worldwide face the ordeal of lung biopsy. As often as possible, doctors performing the procedure use bronchoscopes, instruments snaked into the lungs that carry tiny cameras and surgical tools. The bronchoscope means the biopsy can be done with minimal danger and trauma to the patient. But half the time, the suspected tumor lies so deep in a complex maze of airways that the physician can't reach it. The alternative is an incision through the chest, an operation that increases the danger of collapsed lungs, infection, and even death.



A new image-processing and guidance technology, patented last year by superDimension of Herzliya, Israel, could allow the use of bronchoscopes in far more lung biopsies. The system starts with existing technology that creates 3-D lung images from computerized-tomography (CT) scans. The company's innovation is a method for tracking the location of the bronchoscope in the lung and correlating this information with the 3-D image. A sensor at the bronchoscope's tip wirelessly reports its location to an antenna on a board beneath the patient. As a result, software is able to superimpose the position of the bronchoscope on the virtual 3-D image of the lung, allowing the surgeon to more easily guide the instrument into smaller airways. "With today's practice, many times we can see the problem, but we can't get to it. With this new technique, we can actually go there and see where we are, where we need to be, and which path to take to get us to our target," says David Feller-Kopman, a pulmonary specialist at Beth Israel Deaconess Medical Center in Boston. "It is the future of bronchoscopy."

The system is already approved for use in Europe, where superDimension launched it last fall, and it is now used in Germany and other countries. Approval by the U.S. Food and Drug Administration is expected this summer. SuperDimension says it will market the software and hardware system on its own. The company says that if all goes well, the technology could allow bronchoscope-based procedures in 80 percent of lung biopsies, up from about 50 percent today. If that prediction holds true, and the technology becomes universally available, nearly one million people would be spared major lung surgery every year. **PATRIC HADENIUS**

No. 6,645,455

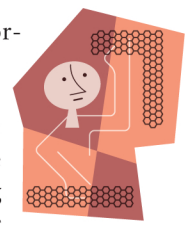
UNTANGLING NANOTECH'S POTENTIAL

Rice University

INVENTION: A method for separating and chemically modifying carbon nanotubes

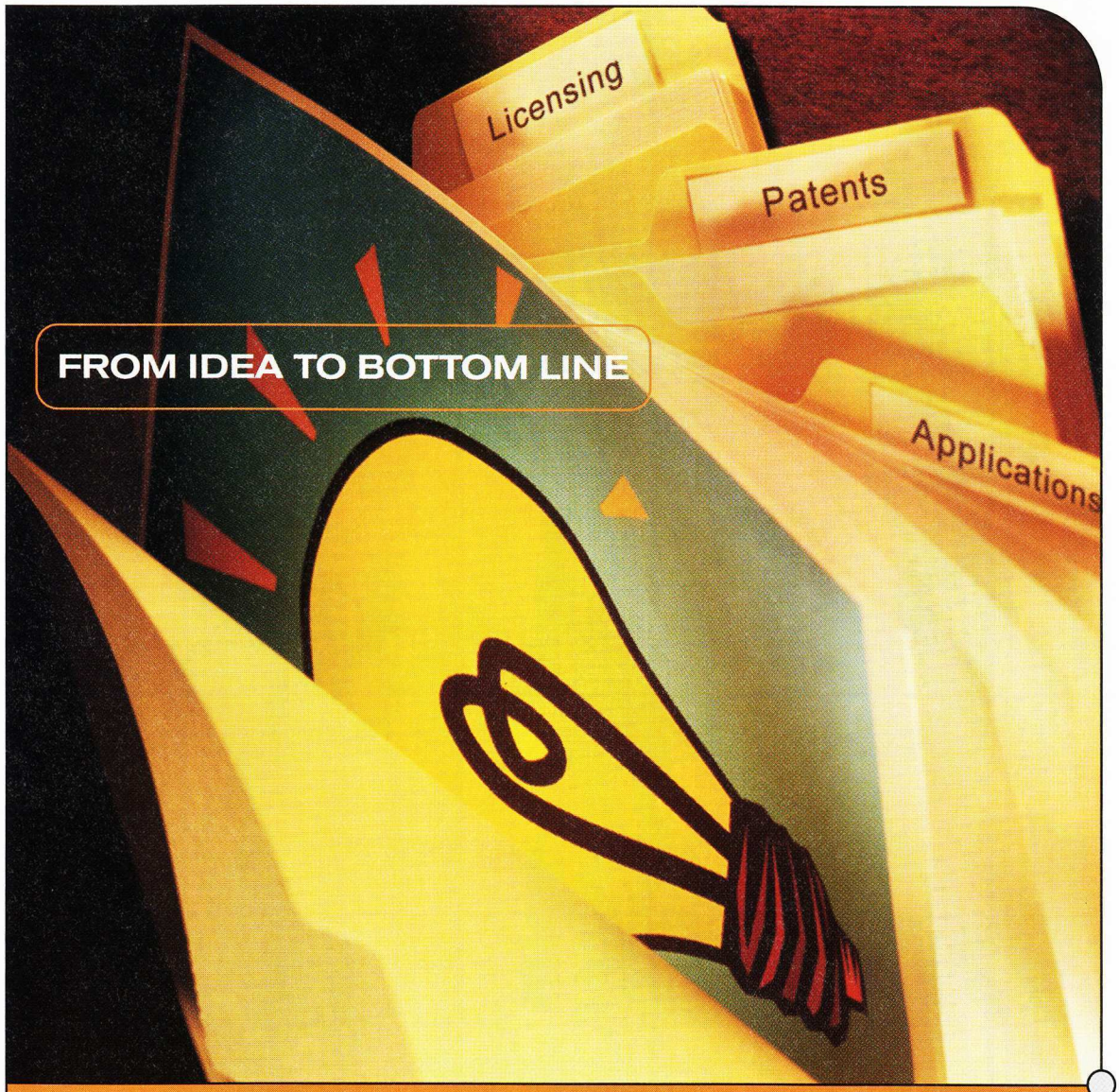
BENEFIT: Could make it easier to use nanotubes in superstrong materials, bright, low-power displays, or ultrasensitive biosensors

CARBON NANOTUBES are the poster molecules of the nanotech revolution—strong, electronically versatile, and no wider than a strand of DNA. They could enable everything from supertough, lightweight materials to ultrasensitive medical diagnostic tests. In their raw state, though, nanotubes tend to clump together in bunches, which makes it difficult to take full advantage of their extraordinary properties. But in the first of a series of inventions aimed at unlocking nanotubes' potential, researchers at Rice University have devised a simple way to untangle and separate them.



The technique involves some straightforward chemistry. Led by Robert Hauge and the late John Margrave, the Rice chemists first exposed carbon nanotubes to fluorine gas. The fluorine binds to the sides of the tubes, making them less sticky and allowing them to be separated from each other. This makes it easier to incorporate the nanotubes into materials, whose strength or electrical conductivity can improve as a result; it is also a key step in using single nanotubes as parts of nanoelectronic devices. "If you want to use nanotubes one by one, you're going to have to do something to the sides, and this allows you to do that," says Richard E. Smalley, a Nobel laureate Rice chemist who collaborated on the work.

Houston-based Rice spinoff CNI, which was cofounded by Smalley, is using the patented technique to modify manufactured batches of the nanotubes that it sells to academic and corporate researchers. While the company is mum on the details of its collaborative efforts to exploit nanotubes, the new separation technique could help the molecules fulfill their revolutionary promise. **ERIKA JONIETZ**



FROM IDEA TO BOTTOM LINE

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The Patent Scorecard 2004

	COMPANY[1]	TECHNOLOGICAL STRENGTH / RANK 2003	RANK	TECHNOLOGICAL STRENGTH / RANK 1998–2002 AVERAGE	RANK	NUMBER OF PATENTS 2003	NUMBER OF PATENTS 1998–2002 AVERAGE	CURRENT-IMPACT INDEX 2003	CURRENT-IMPACT INDEX 1998–2002 AVERAGE	SCIENCE LINKAGE 2003	SCIENCE LINKAGE 1998–2002 AVERAGE	TECHNOLOGY CYCLE TIME 2003	TECHNOLOGY CYCLE TIME 1998–2002 AVERAGE
AEROSPACE	**Lockheed Martin** (U.S.)	356	1	324	2	327	324	1.09	1.00	1.56	2.01	7.8	8.7
	Northrop Grumman (U.S.)	329	2	466	1	375	524	0.88	0.89	0.57	0.67	8.4	8.5
	Boeing (U.S.)	232	3	195	4	272	263	0.85	0.74	0.47	0.60	11.6	12.3
	United Technologies (U.S.)	217	4	235	3	277	351	0.78	0.67	0.12	0.35	11.0	10.6
	Rockwell Automation (U.S.)	111	5	143	5	103	142	1.08	1.01	1.12	0.54	6.7	7.5
	Rockwell Collins (U.S.)	77	6	70	8	73	48	1.05	1.47	0.89	0.57	6.0	6.0
	EADS (Netherlands)	72	7	72	7	148	135	0.49	0.53	0.36	0.36	12.0	11.8
	Thales (France)	56	8	93	6	82	122	0.68	0.76	0.41	0.58	8.7	8.4
	BAE Systems (U.K.)	43	9	32	12	70	56	0.61	0.57	0.54	0.34	9.0	10.7
	Textron (U.S.)	40	10	59	9	54	75	0.74	0.79	0.13	0.25	13.0	11.9
	General Dynamics (U.S.)	35	11	34	11	33	35	1.07	0.95	1.06	2.08	9.1	10.0
AUTOMOTIVE	**Delphi** (U.S.)	773	1	335	8	651	291	1.19	1.15	0.20	0.23	7.2	6.8
	Robert Bosch (Germany)	710	2	578	2	850	680	0.84	0.85	0.12	0.15	7.6	8.0
	Denso (Japan)	676	3	547	5	632	498	1.07	1.10	0.17	0.21	7.0	6.9
	Honda Motor (Japan)	672	4	561	3	696	545	0.97	1.03	0.05	0.10	7.9	7.2
	Ford Motor (U.S.)	497	5	415	7	442	419	1.13	0.99	0.43	0.38	6.7	7.6
	Toyota Motor (Japan)	486	6	559	4	386	433	1.26	1.29	0.26	0.37	5.7	5.8
	General Motors (U.S.)	415	7	477	6	298	438	1.39	1.09	0.50	0.65	6.7	7.4
	Nissan Motor (Japan)	403	8	315	9	315	274	1.28	1.15	0.16	0.07	5.3	6.1
	DaimlerChrysler (Germany)	361	9	608	1	404	627	0.89	0.97	0.11	0.21	7.4	8.9
	Yazaki (Japan)	251	10	268	11	329	319	0.76	0.84	0.02	0.02	6.7	6.9
	Visteon (U.S.)	233	11	101	21	260	96	0.90	1.05	0.16	0.07	7.6	8.5
	Aisin Seiki (Japan)	224	12	250	12	191	195	1.17	1.28	0.08	0.37	5.8	6.0
	Magna International (Canada)	207	13	187	15	116	101	1.78	1.86	0.05	0.60	10.0	10.8
	Siemens VDO Automotive (Germany)	206	14	134	18	232	148	0.89	0.90	0.03	0.04	6.9	8.0
	TRW (U.S.)	177	15	309	10	171	297	1.04	1.04	0.56	0.78	7.8	7.9
BIOTECHNOLOGY/PHARMACEUTICALS	**Pfizer** (U.S.)	312	1	164	4	491	253	0.64	0.65	14.40	6.54	9.6	9.1
	Caliper Technologies (U.S.)	277	2	170	3	47	25	5.90	6.78	11.51	12.30	6.0	5.5
	Affymetrix (U.S.)	178	3	107	10	50	32	3.57	3.38	74.64	45.31	11.4	9.6
	Symyx Technologies (U.S.)	162	4	71	17	45	16	3.59	4.41	16.73	17.78	8.4	7.9
	Roche Holding (Switzerland)	154	5	202	1	312	342	0.50	0.59	16.42	17.72	8.9	8.8
	Bristol-Myers Squibb (U.S.)	130	6	124	7	197	172	0.66	0.72	16.00	14.57	9.0	8.6
	Abbott Laboratories (U.S.)	104	7	110	9	141	161	0.74	0.68	9.19	7.57	9.6	9.6
	Merck (U.S.)	84	8	161	5	162	255	0.52	0.63	13.86	12.27	7.9	6.6
	GlaxoSmithKline (U.K.)	84	9	183	2	189	339	0.44	0.54	7.39	5.78	9.3	8.4
	Maxygen (U.S.)	80	10	133	6	23	11	3.47	12.28	147.43	113.91	5.4	4.2
	Diversa (U.S.)	76	11	97	13	13	11	5.86	8.52	16.46	7.88	5.8	4.6
	Nektar Therapeutics (U.S.)	61	12	24	41	18	12	3.39	1.96	14.72	7.87	12.3	9.6
	Elan (Ireland)	59	13	37	31	55	41	1.08	0.91	29.67	13.41	10.4	10.0
	Aventis Pharma (Germany)	51	14	94	16	181	261	0.28	0.36	14.15	10.22	11.0	9.8
	AstraZeneca (U.K.)	51	15	96	14	114	192	0.44	0.50	7.45	6.89	9.6	8.5
	General Hospital (U.S.)	50	16	49	21	74	70	0.67	0.70	38.97	37.91	7.6	7.8
	Novartis (Switzerland)	47	17	114	8	119	220	0.40	0.52	7.93	10.31	11.3	9.4
	Eli Lilly (U.S.)	46	18	103	11	106	164	0.43	0.63	15.75	7.89	8.7	8.8
	Vertex Pharmaceuticals (U.S.)	45	19	34	36	44	24	1.03	1.38	6.98	20.96	7.8	7.7
	Schering-Plough (U.S.)	42	20	63	19	75	90	0.56	0.70	11.31	13.59	6.3	7.9
	Embol-X[2] (U.S.)	39	21	47	24	5	14	7.82	3.39	1.40	2.90	5.8	6.3
	Corixa (U.S.)	37	22	13	55	44	18	0.85	0.74	16.84	14.71	5.3	7.1
	Emisphere Technologies (U.S.)	35	23	44	26	9	19	3.93	3.88	9.00	135.49	5.8	12.9
	Schering (Germany)	35	24	95	15	61	98	0.57	0.97	5.59	6.13	9.8	8.6
	Genzyme (U.S.)	32	25	49	22	33	42	0.98	1.16	12.39	17.37	9.7	8.9
CHEMICALS	**3M** (U.S.)	829	1	616	2	593	522	1.40	1.18	2.64	2.54	11.3	11.1
	Procter and Gamble (U.S.)	581	2	662	1	474	479	1.23	1.38	1.55	1.69	11.2	10.7
	DuPont (U.S.)	241	3	294	4	433	481	0.56	0.61	5.79	5.02	10.8	10.8
	Bayer (Germany)	222	4	271	5	546	616	0.41	0.44	2.65	3.10	10.9	10.1
	BASF (Germany)	212	5	301	3	494	668	0.43	0.45	1.41	1.94	10.4	10.4
	Bridgestone (Japan)	199	6	173	7	183	186	1.09	0.93	0.25	0.61	7.8	9.8
	Shin-Etsu Chemical (Japan)	152	7	148	8	203	211	0.75	0.70	0.70	0.54	6.5	7.3
	Sumitomo Rubber (Japan)	141	8	73	27	128	80	1.11	0.91	0.02	0.03	7.5	7.4
	Henkel (Germany)	129	9	112	13	124	170	1.04	0.66	0.48	1.05	11.4	11.9
	Dow Chemical (U.S.)	127	10	194	6	200	249	0.64	0.78	7.13	4.59	12.8	10.6
	Rohm and Haas (U.S.)	122	11	145	9	159	162	0.77	0.89	0.89	0.86	9.2	9.0
	Merck (Germany)	111	12	64	31	143	93	0.78	0.69	1.08	1.24	7.8	6.4
	Toyoda Gosei (Japan)	110	13	80	21	92	70	1.20	1.14	0.95	0.42	6.1	6.8
	Degussa (Germany)	99	14	115	12	200	235	0.50	0.49	1.28	0.96	9.8	10.0
	Goodyear Tire and Rubber (U.S.)	92	15	82	20	174	125	0.53	0.66	0.11	0.14	12.2	12.8
	Praxair (U.S.)	90	16	79	24	82	84	1.10	0.94	0.43	0.69	7.3	8.3
	Cabot (U.S.)	89	17	122	10	41	37	2.17	3.27	3.22	4.28	11.3	11.4
	Sumitomo Chemical (Japan)	84	18	79	23	199	189	0.42	0.42	1.88	1.67	8.6	9.2
COMPUTERS	**IBM** (U.S.)	5,386	1	5,905	1	3,434	3,044	1.57	1.94	0.98	1.01	5.5	5.6
	Hewlett-Packard (U.S.)	2,778	2	2,571	2	1,755	1,339	1.58	1.92	0.54	0.94	5.7	5.7
	Fujitsu (Japan)	1,685	3	1,607	4	1,460	1,275	1.15	1.26	0.49	0.58	5.7	5.7
	NEC (Japan)	1,445	4	2,136	3	1,666	1,942	0.87	1.10	0.58	0.67	5.2	4.9
	Microsoft (U.S.)	1,175	5	1,223	5	528	405	2.23	3.02	2.85	2.90	5.4	4.5
	Sun Microsystems (U.S.)	1,088	6	1,165	6	569	481	1.91	2.42	1.99	2.15	5.3	4.9
	Cisco Systems (U.S.)	1,080	7	564	9	358	130	3.02	4.33	1.69	1.74	6.3	6.0
	Seiko Epson (Japan)	912	8	585	8	780	437	1.17	1.34	0.44	0.81	5.9	7.0
	Ricoh (Japan)	716	9	448	11	438	411	1.64	1.09	0.31	0.33	5.4	5.9
	Xerox (U.S.)	710	10	902	7	621	688	1.14	1.31	0.94	1.00	7.4	7.0
	Seagate Technology (U.S.)	565	11	400	13	411	265	1.37	1.51	0.66	0.96	6.9	6.6

Hon Hai Precision (Taiwan)	537	12	553	10	397	291	1.35	1.90	0.00	0.00	3.8	4.0
3Com (U.S.)	478	13	432	12	208	150	2.30	2.87	0.72	0.53	5.2	5.0
EMC (U.S.)	380	14	239	18	141	87	2.70	2.73	1.20	1.63	5.8	5.3
International Game Technology (U.S.)	380	15	65	39	72	22	5.28	3.02	0.06	0.05	4.3	6.2
Digimarc (U.S.)	304	16	97	30	50	13	6.09	7.58	19.16	29.16	8.9	8.3
Dell (U.S.)	297	17	287	16	131	106	2.27	2.71	0.14	0.07	5.6	5.1
Oki Electric (Japan)	282	18	304	15	337	279	0.84	1.09	0.33	0.38	5.0	5.2
NCR (U.S.)	247	19	257	17	166	162	1.49	1.59	0.86	0.69	7.7	6.8
Oracle (U.S.)	185	20	197	19	87	75	2.13	2.62	1.09	1.61	4.6	3.8
Western Digital (U.S.)	158	21	61	41	82	38	1.93	1.61	0.40	0.39	5.3	5.1
Fuji Xerox (Japan)	152	22	193	20	177	213	0.86	0.91	1.07	0.69	5.6	5.2
Unisys (U.S.)	141	23	166	23	99	108	1.42	1.53	0.44	0.55	6.3	5.8
Apple Computer (U.S.)	132	24	318	14	82	140	1.61	2.27	1.41	1.25	5.5	5.4
ELECTRONICS												
Hitachi (Japan)	2,747	1	1,859	2	2,189	1,487	1.25	1.25	0.55	0.69	6.5	6.7
Matsushita Electric (Japan)	1,940	2	1,543	6	1,944	1,456	1.00	1.06	0.46	0.53	6.0	6.1
Canon (Japan)	1,911	3	1,983	1	2,061	1,925	0.93	1.03	0.64	0.52	7.1	7.7
Toshiba (Japan)	1,608	4	1,697	3	1,356	1,326	1.19	1.28	0.50	0.58	5.5	5.8
Sony (Japan)	1,413	5	1,656	5	1,539	1,465	0.92	1.13	0.41	0.41	5.9	5.6
Samsung (South Korea)	1,396	6	1,677	4	1,577	1,613	0.89	1.04	0.25	0.20	5.3	5.4
General Electric (U.S.)	1,379	7	899	10	1,457	1,058	0.95	0.85	2.19	2.36	9.4	9.9
Philips Electronics (Netherlands)	1,354	8	1,141	9	1,416	1,097	0.96	1.04	0.50	0.60	5.8	5.9
Mitsubishi Electric (Japan)	1,289	9	1,352	7	1,352	1,218	0.95	1.11	0.43	0.53	5.7	5.7
Siemens (Germany)	1,172	10	1,211	8	1,352	1,346	0.87	0.90	0.53	0.86	7.3	7.2
Sharp (Japan)	689	11	707	11	637	614	1.08	1.15	0.85	0.80	5.4	5.3
Agilent Technologies (U.S.)	529	12	230	17	403	169	1.31	1.36	0.85	1.51	6.2	6.3
Tyco International (U.S.)	477	13	564	12	394	470	1.21	1.20	0.68	0.67	10.9	9.9
LG Electronics (South Korea)	401	14	250	16	465	305	0.86	0.82	0.15	0.20	5.2	5.3
Murata (Japan)	358	15	289	14	448	310	0.80	0.93	0.21	0.23	6.1	7.1
Sanyo Electric (Japan)	339	16	263	15	387	286	0.88	0.92	0.16	0.37	5.6	5.7
Tokyo Electron (Japan)	307	17	383	13	211	182	1.46	2.11	1.28	0.40	6.4	6.0
LG Philips LCD (South Korea)	294	18	72	36	227	46	1.29	1.57	1.01	1.82	5.3	4.9
Emerson Electric (U.S.)	293	19	198	20	218	209	1.34	0.95	4.03	1.66	10.4	10.5
Alps Electric (Japan)	286	20	193	22	279	201	1.03	0.96	0.08	0.04	5.3	5.7
Pioneer (Japan)	280	21	200	18	253	187	1.11	1.07	0.30	1.45	6.4	7.8
SEMICONDUCTORS												
Micron Technology (U.S.)	3,320	1	3,292	1	1,712	1,366	1.94	2.41	2.39	2.15	6.6	5.8
Intel (U.S.)	2,688	2	1,857	3	1,606	848	1.67	2.19	1.01	0.87	5.3	5.2
Advanced Micro Devices (U.S.)	1,281	3	1,900	2	908	936	1.41	2.03	0.65	0.78	4.4	4.7
Samsung Electronics (South Korea)	1,228	4	1,624	4	1,363	1,504	0.90	1.08	0.25	0.19	5.3	5.3
Applied Materials (U.S.)	1,203	5	942	6	551	378	2.18	2.49	2.45	1.69	6.7	7.2
Texas Instruments (U.S.)	1,101	6	1,096	5	784	726	1.40	1.51	0.80	1.18	6.0	6.4
Semiconductor Energy Laboratory (Japan)	716	7	589	11	279	189	2.57	3.12	4.99	3.07	7.0	6.5
LSI Logic (U.S.)	669	8	685	9	377	322	1.77	2.13	0.68	1.28	5.0	5.5
Infineon Technologies (Germany)	627	9	176	22	729	184	0.86	0.96	0.59	0.45	5.4	5.0
Taiwan Semiconductor (Taiwan)	626	10	934	7	437	430	1.43	2.17	0.23	0.23	4.5	4.1
STMicroelectronics (France)	439	11	559	12	552	538	0.79	1.04	0.70	0.90	6.2	6.5
Broadcom (U.S.)	433	12	54	37	174	30	2.49	1.82	3.29	2.03	5.4	5.2
Hynix Semiconductor (South Korea)	387	13	691	8	448	581	0.86	1.19	0.40	0.40	5.0	5.0
Amkor Technology (U.S.)	348	14	117	26	89	34	3.91	3.47	0.06	0.38	5.4	5.0
National Semiconductor (U.S.)	271	15	308	13	217	196	1.25	1.57	0.91	1.07	5.5	5.7
Lam Research (U.S.)	243	16	205	19	132	80	1.84	2.56	0.31	1.15	6.7	6.4
Novellus Systems (U.S.)	223	17	66	36	73	24	3.06	2.78	1.16	1.45	5.9	7.7
Macronix International (Taiwan)	221	18	109	27	182	50	1.21	2.17	0.08	0.62	4.0	4.7
Xilinx (U.S.)	218	19	255	16	137	111	1.59	2.30	0.67	1.47	5.3	5.5
Chartered Semiconductor (Singapore)	202	20	265	14	100	91	2.02	2.90	0.38	0.20	4.6	3.9
Cypress Semiconductor (U.S.)	196	21	189	20	193	120	1.01	1.57	0.68	1.18	6.5	6.2
TELECOMMUNICATIONS												
Lucent Technologies[3] (U.S.)	971	1	1,944	1	641	1,144	1.51	1.70	1.47	1.34	5.1	5.4
Motorola (U.S.)	959	2	1,759	2	661	1,113	1.45	1.58	2.83	1.00	5.7	5.4
Ericsson (Sweden)	940	3	1,277	3	654	683	1.44	1.87	1.01	1.00	5.6	5.5
Nortel Networks (Canada)	882	4	809	4	465	408	1.90	1.98	3.69	1.07	5.0	4.7
Nokia (Finland)	821	5	611	6	511	323	1.61	1.89	0.60	0.48	5.6	5.2
Qualcomm (U.S.)	522	6	507	7	182	139	2.87	3.64	1.11	0.97	7.6	6.8
Alcatel (France)	416	7	479	8	381	410	1.09	1.17	0.67	0.80	5.6	6.3
AT&T (U.S.)	412	8	680	5	211	264	1.95	2.57	1.36	1.15	5.2	4.7
Agere (U.S.)	384	9	172	13	335	158	1.15	1.09	1.03	1.30	5.5	5.1
JDS Uniphase (U.S.)	273	10	213	11	117	105	2.33	2.02	1.52	2.58	7.3	6.8
Verizon Communications (U.S.)	258	11	358	9	91	96	2.84	3.71	1.34	1.53	5.7	6.2
ADC Telecommunications (U.S.)	247	12	83	24	122	44	2.02	1.89	0.51	1.07	8.7	7.5
WorldCom (U.S.)	183	13	264	10	74	103	2.47	2.57	1.36	1.15	5.1	4.5
BellSouth (U.S.)	173	14	98	19	89	35	1.95	2.78	0.35	0.20	5.4	5.5
Sprint (U.S.)	150	15	88	23	63	25	2.38	3.54	2.70	7.84	7.7	6.5

Indexing Innovation

Technology Review has teamed with CHI Research of Haddon Heights, NJ, to produce the Patent Scorecard, an industry-by-industry ranking of corporate patent portfolios. CHI combines the number of patents a company receives with other indicators to flesh out this deeper picture of innovation. Here are the specifics:

TECHNOLOGICAL STRENGTH: This figure, the basis of the rankings, provides an overall assessment of a company's intellectual-property power. It is calculated by multiplying the number of a company's U.S. patents by its current-impact index *(see below)*.

NUMBER OF PATENTS: The number of U.S. patents awarded, excluding design and other special-case inventions.

CURRENT-IMPACT INDEX: This measure showcases the broader significance of a company's patents by examining how often its U.S. patents from the previous five years are cited as prior art in the current year's batch. A value of 1.0 represents average citation frequency, so, for example, a value of 1.4 would indicate a company's patents were cited 40 percent more often than the average.

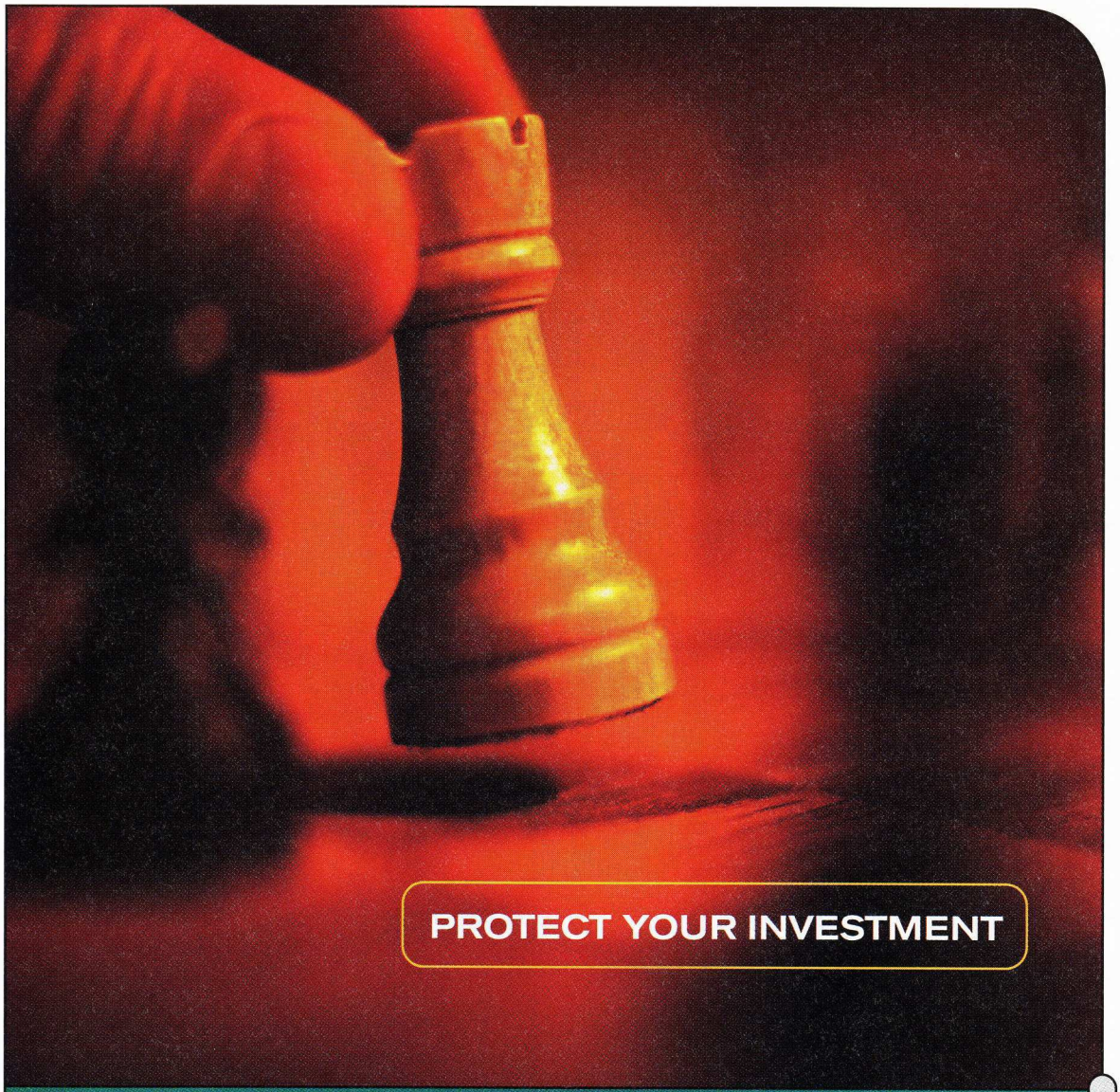
SCIENCE LINKAGE: Some patents cite scientific papers as prior art. This value shows the average number of scientific references listed in a company's U.S. patents. A high figure indicates a company closer to the cutting edge than competitors with lower values.

TECHNOLOGY CYCLE TIME: This indicator of a firm's speed in turning leading-edge technology into intellectual property is defined as the median age (in years) of the U.S. patents cited as prior art in the company's patents.

FOOTNOTES

1. Figures include values for all subsidiaries and wholly owned companies.
2. Embol-X was acquired in 2003 by Edwards Lifesciences, which is not listed on the scorecard.
3. Patent total may include patents reassigned to Avaya after it spun off from Lucent in 2000.

An expanded version of the scorecard lists more companies and is available at **www.technologyreview.com/scorecards/.**



BUILD UPON ADVANTAGE

When intellectual property disputes threaten the future of your business, leave nothing to chance. Turn to Hale and Dorr to protect what is yours.

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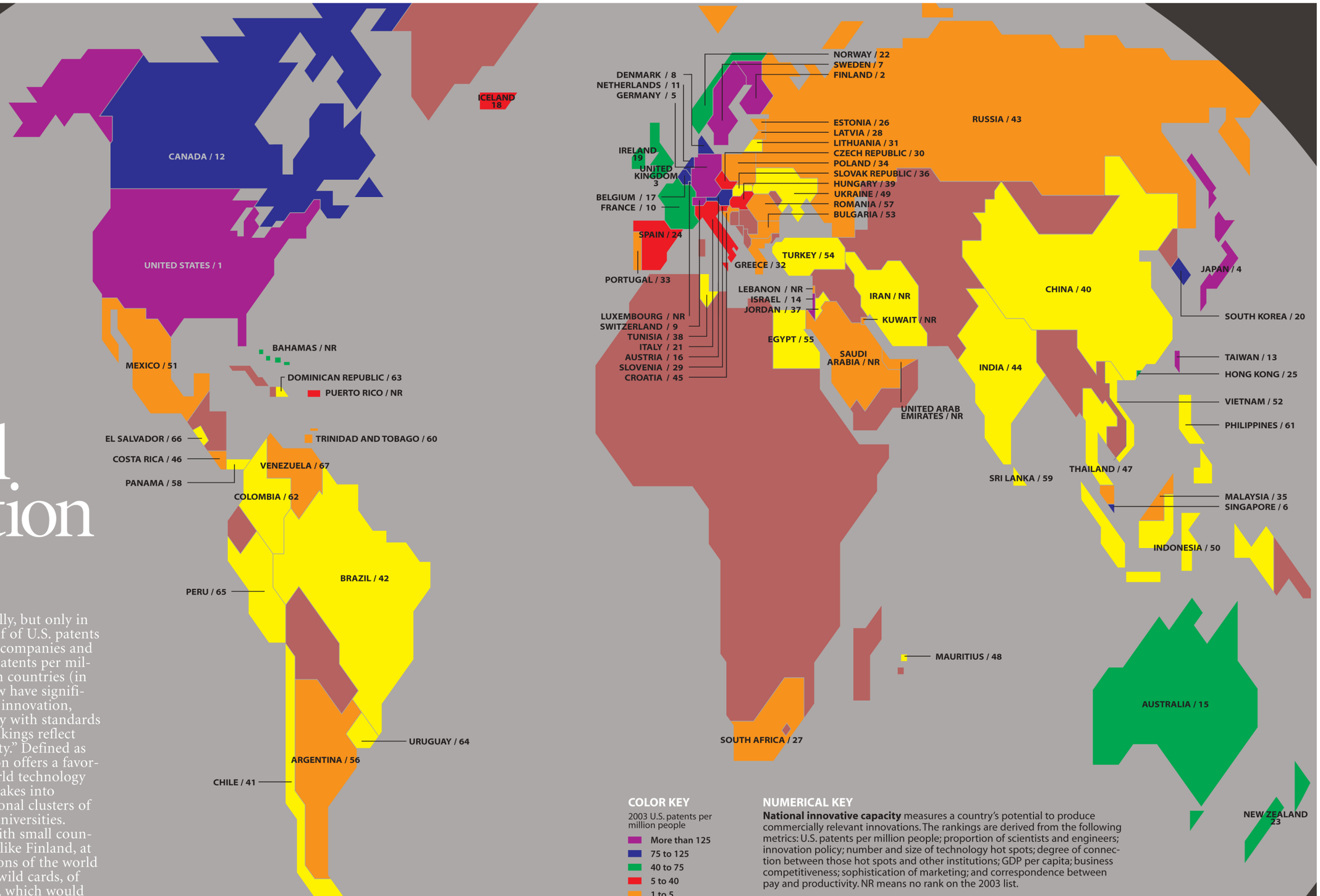
Global Invention Map

INVENTION IS exploding globally, but only in certain hot spots. Nearly half of U.S. patents are now awarded to foreign companies and inventors. As measured by patents per million people, some two dozen countries (in purple, blue, and green) now have significant levels of invention and innovation, activity that correlates highly with standards of living. The numerical rankings reflect "national innovation capacity." Defined as "the degree to which a nation offers a favorable environment at the world technology frontier," this measure also takes into account the strength of regional clusters of innovative companies and universities. There are some surprises, with small countries ranking near the top—like Finland, at number two—and vast regions of the world still hardly registering. The wild cards, of course, are India and China, which would remake the map if their already significant levels of innovation grew to be more commensurate with their vast populations.

ILLUSTRATION BY GREG MABLY



COLOR KEY

2003 U.S. patents per million people

- More than 125
- 75 to 125
- 40 to 75
- 5 to 40
- 1 to 5
- Less than 1
- No data

SOURCES: CHI RESEARCH, U.S. PATENT AND TRADEMARK OFFICE, CIA WORLD FACTBOOK 2003

NUMERICAL KEY

National innovative capacity measures a country's potential to produce commercially relevant innovations. The rankings are derived from the following metrics: U.S. patents per million people; proportion of scientists and engineers; innovation policy; number and size of technology hot spots; degree of connection between those hot spots and other institutions; GDP per capita; business competitiveness; sophistication of marketing; and correspondence between pay and productivity. NR means no rank on the 2003 list.

SOURCE: MICHAEL PORTER OF HARVARD BUSINESS SCHOOL AND SCOTT STERN OF NORTHWESTERN UNIVERSITY AND THE NATIONAL BUREAU OF ECONOMIC RESEARCH

Face Forward

BY ERIKA JONIETZ

In today's security-conscious world, better access control—whether it's a company restricting entry into its building or a government monitoring entry into a country—has become a priority. One solution gaining popularity is biometrics, systems that use specific biological traits such as fingerprints or facial features to identify individuals. Face recognition is an especially appealing technique, because capturing an image of the face is simple and nonintrusive. But using face recognition for applications such as border control can require querying a database of thousands to millions of photos, which is time consuming and raises privacy concerns.

OMNIPERCEPTION

HEADQUARTERS: Surrey, England

UNIVERSITY: Surrey

INVESTMENT RAISED: $940,000

LEAD INVESTORS: University of Surrey, U.K. government

KEY FOUNDERS: Josef Kittler, Charles Galambos, Kieron Messer

To get around these problems, OmniPerception, a spinoff from the University of Surrey in England, has combined its facial-recognition technology with a smart-card system. This could make face recognition more robust and better suited to applications such as passport authentication and building access control, which, if they use biometrics at all, rely mainly on fingerprint verification, says David McIntosh, the company's CEO. With OmniPerception's technology, an image of a person's face is verified against a "facial PIN" carried on the card, eliminating the need to search a central database and making the system less intimidating to privacy-conscious users.

Josef Kittler, head of the Centre for Vision, Speech, and Signal Processing at the University of Surrey, founded the company in 2001. OmniPerception is now collaborating with a Spanish firm to test its technology in controlling access to secure areas at a mint. It's also working with IBM on possible pilot trials for the British government's project to use biometrics with its passports. One of OmniPerception's biggest deals is with Japan's Sharp Electronics, which is incorporating the technology into its own smart cards, which are themselves used in Japan as national ID cards.

While combining biometrics, such as fingerprinting, with smart cards isn't new, OmniPerception is among the first to move facial recognition on smart cards to market. And not having to transmit biometric images to a central database is better for security, says Anil Jain, a biometrics researcher at Michigan State University. "You don't want to transmit your face image," he says. "Somebody may intercept it" and use it for identity theft.

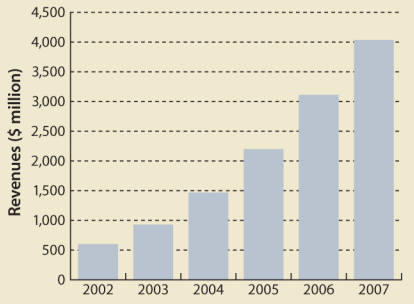
OmniPerception's technology creates a PIN about 2,500 digits long from its analysis of the most distinctive features of a person's face. The number is embedded in a smart card—such as those, say, that grant access to a building—and used to verify that the card belongs to the person presenting it. A user would place his or her card in or near a reader and face a camera, which would take a photo and feed it to the card. The card would then compare the PIN it carried to information it derived from the new photo and either accept or reject the person as the rightful owner of the card. The technology could also be used to ensure passport or driver's license authenticity and to secure ATM or Internet banking transactions, says McIntosh.

The key differences between the various face recognition systems hitting the market reside mainly in the algorithms that create digital code from their analysis of faces. Kittler says his algorithms require less computation, allowing all the processing to happen on the card, instead of in an external computer, which results in nearly instantaneous identity verification. Fast processing would be particularly useful at, for example, a busy airport or ATM.

Biometrics companies typically validate their technologies by participating in competitions that test their accuracy at identification. OmniPerception won a European competition last year but has yet to go head-to-head with more prominent U.S. players in the field's premier competition, which is sponsored by the U.S. government. And it must also contend with more established biometric techniques—namely fingerprinting.

Even so, with plans to demonstrate its technology this year to U.S. passport authorities, British and U.S. driver's-license agencies, and security companies worldwide, OmniPerception believes it has a head start toward the future of face recognition.

GLOBAL BIOMETRIC REVENUES



SOURCE: INTERNATIONAL BIOMETRIC GROUP (REVENUES)

OTHERS IN FACIAL RECOGNITION

COMPANY	TECHNOLOGY
A4Vision (Cupertino, CA)	3-D facial recognition for access control and surveillance
Acsys Biometrics (Burlington, Ontario)	Neural-network facial recognition for building and border access control
Identix (Minnetonka, MN)	Facial-feature analysis for access control and surveillance
Viisage (Littleton, MA)	"Eigenface" technology for access control and surveillance

TiVo

When TiVo's digital video recorder (DVR) hit the market in 1999, it transformed the way people watched television. No longer slaves to network schedules, viewers could watch any programs they wanted at any time of day, pause and rewind at will, and—the *coup de grace*—fast-forward through commercials. At the heart of the system is a computer hard drive that stores television shows as digital files; a subscription-based service updates schedules and practically does the recording for you. The company has teamed up with satellite service provider DirecTV to produce both a satellite receiver integrated with a DVR and a DirecTV high-definition DVR, to be released in April. Other DVR offerings in the market include ReplayTV and services available through cable and satellite companies. **TEXT AND ART BY 5W INFOGRAPHIC**

HARDWARE

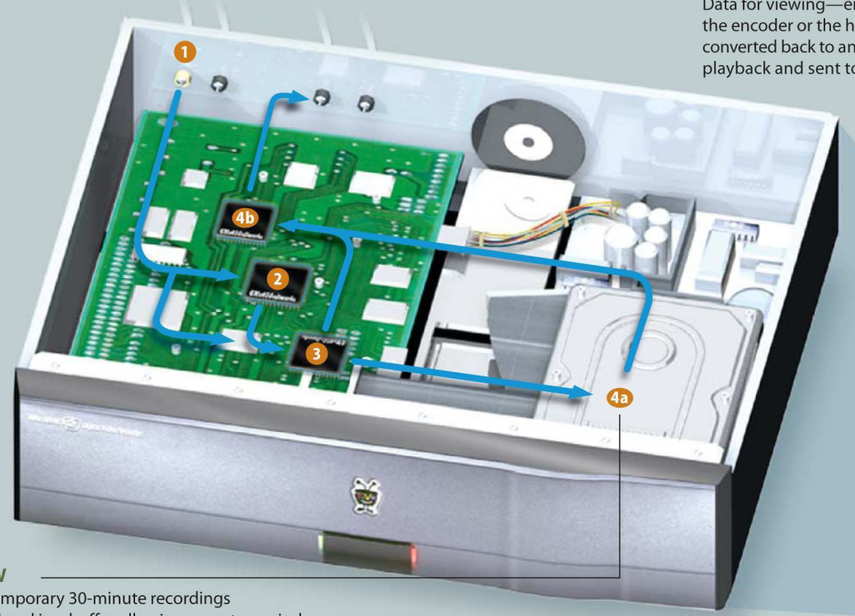
1 SIGNAL
Signals coming from an antenna, cable, or satellite receiver travel through a port at the back of the DVR box.

2 TUNER
Signals from an antenna flow into the tuner, which selects the frequency of the desired channel and sends its signal on. Signals coming from cable boxes or satellite receivers bypass TiVo's tuner.

3 ENCODER
The encoder converts the signal to digital and then compresses it for storage as an MPEG-2 file, the same format used to store video on DVDs. The MPEG-2 data travels on to two places.

4a HARD DRIVE
Data to be stored goes to TiVo's hard drive, which can hold as much as 140 hours of programming.

4b DECODER
Data for viewing—either from the encoder or the hard drive—is converted back to analog for playback and sent to the TV.



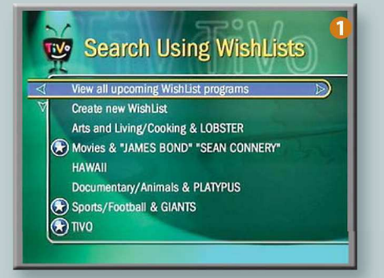
RECORD LIVE TV
The unit makes temporary 30-minute recordings of the incoming signal in a buffer, allowing users to rewind or pause programs as they air *(see below)*. Each time the user switches the channel, the buffer empties, and the unit begins to record the new show. TiVo users can avoid commercials by tuning into their programs 15 to 20 minutes after they start and then fast-forwarding during the breaks. The DirecTV recorder comes with two built-in tuners that let users record two live programs at the same time or watch one while recording another.

TiVo can record at four different levels of compression, providing from 230 to 430 lines of horizontal resolution.

SERVICE

TiVo program guide services let users interact with their televisions in new, almost unlimited ways.

PROGRAM GUIDE
TiVo Inc. purchases program listings from Tribune Media Services. The TiVo unit dials into a server nightly via a phone line or broadband connection and downloads two weeks' worth of program-guide data for the owner's cable or satellite provider. These nightly updates enable TiVo to detect changes in program listings and adjust recording times accordingly. The unit can also receive software updates during these calls.



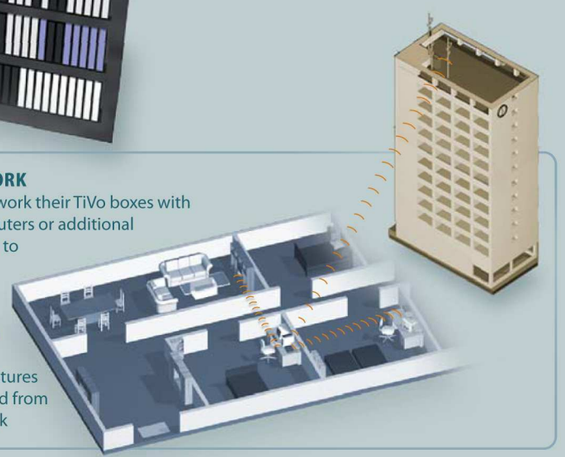
1 WISH LIST
Users can instruct TiVo to record by program name, genre, or other, more complex parameters, creating a "wish list" of desired shows. For example, the system might look for movies starring Sean Connery, or programs with "platypus" in the title.

2 SEASON PASS
TiVo can be programmed to record every episode of a show on any given channel. A viewer who does not want to watch reruns can specify only first-run episodes.

3 SMART RECORDING
Users can rate details of a program, including genre, actors, director, writers, and episodes, by pressing a "thumbs up" or a "thumbs down" button on the remote control. TiVo saves the scores on the hard drive and uses a statistical algorithm that takes into account all of the stored information to make suggestions about what programs a viewer might like in the future. Users can either ask TiVo to make lists of viewing suggestions or authorize it to auto-record the recommended shows.

CREATING A TIVO NETWORK
Software now lets users network their TiVo boxes with other devices, such as computers or additional TiVo boxes. This allows them to

- Program TiVo from anywhere via the Internet
- Transfer programs from one TiVo unit to another in the house
- Use TiVo to view digital pictures and listen to MP3s accessed from a computer via the network



The Paper Killer

I NEVER BEFORE BELIEVED THE CLAIMS OF COMpanies that sell optical character recognition (OCR) software—those programs that turn scans of printed pages into editable text. That's because I know how to multiply. When the companies claimed "99 percent accuracy," I translated that to roughly one error on every line. And that, in my opinion, was unacceptable. ■ Then last fall, I had a revelatory experience. I was trying to sell an old book of dolls on eBay, so I scanned a page and told Microsoft Office Document Scanning to save it as an image. When the program prompted me for a file name, the name it suggested corresponded to the scanned page's headline.

Funny, I didn't remember typing in that headline.

On a whim, I saved the page as a Microsoft Word document. Then I opened the file and compared it to the original. There was not a single error in five paragraphs of text. Optical character recognition software has done a lot of growing up in the past ten years. A lot of people don't realize just how good the technology has become because they base their impressions on the free software that comes with scanners rather than on professional-grade software, which costs hundreds of dollars. But after I wrote last year about how I was scanning all of my old documents into PDF files *(see "Slaying the Paper Dragon," TR October 2003)*, a publicist at Abbyy USA sent me the company's FineReader 7.0 corporate edition.

My test was simple: I fed the software my bank statement. FineReader spent 15 seconds scanning the page and another 30 turning the image into text.

Modern character recognition systems use a variety of mathematical techniques to perform their magic. Imaging algorithms remove speckles and rotate the page so that it's "straight." Then a series of algorithms separates out each glyph, determines the likelihood that any glyph is a particular letter, and consults a dictionary to come up with a probable word. The software can also decide to accept a word that's not in the dictionary, if the image looks good and there are no obvious close matches.

The cost of optical character recognition software is far lower than that of the alternative: hiring a typist.

Optical character recognition has made such strides in recent years for much the same reason that speech recognition and machine translation systems have: fast computers with massive memories allow software to evaluate many alternative hypotheses when it's trying to recognize words. Programs can consult statistical models created by analyzing millions of pages of text and pick hypotheses that have the greatest chance of being correct. And the explosion of the Web has provided millions of pages of text from which to compile the statistics.

Because these techniques have become widespread, I wasn't surprised that FineReader could correctly recognize the legalese that my bank printed at the bottom of the statement. What surprised me was that it could handle the rest of the page: it recognized my street address, the names of companies that had received electronic payments, and even the dollars and cents of every returned check. The reason this is so amazing is that FineReader can't use dictionary lookups to improve its accuracy on these items; it has to get them right based on image processing alone.

I also experimented with OmniPage Pro, a similar program from ScanSoft. Like FineReader, OmniPage allows you to manually review and correct errors, spell-check the OCRed document, and save the resulting scan in a variety of formats—including Microsoft Word, HTML, and PDF.

PDF is the best for my purposes, because it's the only format that allows me to save both the original page and the OCRed text in a single file. I need the original image in case I get audited. But a computer can't search for individual words in an image; for that you need text. A PDF file made from a Microsoft Word document can be searched because the text has already been entered letter by letter; a scanned-in document, however, is unsearchable unless you run OCR.

Based on my OCR experience, I'm now going through my last seven years of bank statements. Each year gets loaded into my sheet feeder, scanned, and OCRed into a single file. If I ever need to find something, I'll just perform a computer search for it; in my tests, searching is faster than manually paging through the paper statements. I've also started scanning my deceased father-in-law's poetry and other writings from the 1960s and '70s. I always intended to put this material online—and with OCRed text, Google will find it. The modest cost of the optical character recognition software is far, far, lower than that of the alternative: hiring a typist.

And optical character recognition is going to get even better within the next few years. Techniques under development will use grammatical models of English and other languages to disambiguate words that are visually similar but grammatically different—words like "bottom" and "button." Should I want, I'll be able to open those PDFs and reprocess them.

I'm slowly getting rid of the paper dragon in my basement. At this rate, I may really be paperless by 2005.

Simson Garfinkel is an incurable gadgeteer, an entrepreneur, and the author of 12 books on information technology and its impact.

Annual IP Law Resource Guide

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People and organizations mentioned in this issue

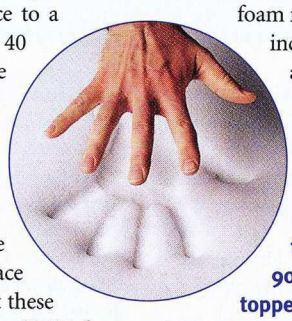
CLOUD 10

Where Every Night's Sleep is a Perfect 10

I had a great night in bed last night...I slept!

CLOUD 10 has found a way to give you the same great sleep technology as a $2500 visco-elastic foam mattress for a price starting at less than $100

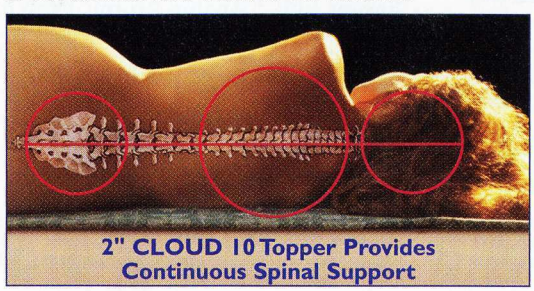
There is a revolution going on in the bedroom. It's not between the sheets...it's under them! The sleep surfaces of traditional metal spring mattresses are proving to be a hindrance to a good night's rest. So for the 40 million Americans who have difficulty sleeping, your best bet—until now—has been to buy a new visco-elastic mattress. Visco-elastic foam uses a technology first developed by NASA to make the most comfortable sleep surface ever. The only problem is that these mattresses routinely cost about $2500 for a queen size. Most of us wouldn't sleep well if we added that cost to our credit card!



If you own a decent mattress, don't throw it out—make it better! Add the CLOUD 10 Mattress topper and rejuvenate that mattress. The CLOUD 10 is a mattress topper made from 2 inches of heat sensitive visco-elastic memory foam. This material reacts to your body temperature, so the surface stays cool in the summer and warm in the winter. It creates a contoured surface that cradles your body and helps eliminate those pressure points created by traditional mattress surfaces. When we tried the visco-elastic foam mattress topper, the feeling was incredible. "My neck and back felt as if they were floating and the pain in my aching joints was reduced. Even my legs were much more comfortable."

The CLOUD 10 mattress topper lets you experience the most restorative sleep for 90% less cost than a visco-foam topped mattress.

You may have seen the visco-foam mattress story on TV but the secret is that only the top 2-3 inches of their $2500 mattress is actually the technologically advanced visco-elastic foam. The rest of the mattress is standard foam. Well, you only sleep on the top two inches of your mattress, so we think that you should get the great benefits of visco-foam at prices starting under $100. Simply place the CLOUD 10 on top of your current mattress. We were able to make this price possible by working directly with the largest United States visco-foam manufacturer.



2" CLOUD 10 Topper Provides Continuous Spinal Support

We sent the CLOUD 10 to renowned Neurosurgeon Dr. William Beutler, and he believes that the CLOUD 10 technology will cradle your body in such a way that can help reduce compression on the spine and relieve joint pain. Less pain has been linked to better sleep continuity and deeper sleep patterns. As you age, your cartilage is reduced and musculoskeletal aching increases. Therefore, it is necessary to give the sleeping body more continuous support—CLOUD 10 does exactly that!

Exclusive 99 night in-home trial. We are so sure that CLOUD 10 will improve the one third of your life that is spent in bed that we will offer you a no-questions asked in-home trial for 99 nights. If you're not sleeping significantly better and waking refreshed, send the mattress topper back for a full refund of the purchase price.

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More Accurate than Einstein's Theory

The classic watch built with German precision to 1 billionth of a second

There is a new super-accurate government device that gives you a perfect use for atomic theory. The US government has engineered the most ingenious, most accurate clock in the world, the new F-1 U.S. Atomic Clock in Boulder, Colorado. Our extraordinary new Stauer EMC^2 watch uses this clock to report the exact time from this remarkable cesium fission clock. So you are on time…all the time. This amazing timepiece will gain or lose only one second over a twenty million-year period. It is that accurate!

This perfectly tuned technological invention is now available for UNDER $100. And you'll never have to set this watch…the hands set themselves. Just push one of the buttons and you are synchronized with the F-1 and the hands of the watch move to the exact time position. The Stauer EMC^2 exceeds the accuracy of any Swiss luxury automatic so you can be more accurate and keep most of your money in your wallet… not on your wrist.

There are some unattractive plastic digital atomic watches on the market, but when our German movement maker made it possible for us to break the $100 price barrier with a beautiful, classically styled stainless steel analog watch, we were truly excited.

The EMC^2 features precise atomic time with an automatic Standard time and Daylight Saving Time adjustment. It will adjust for leap years and even leap seconds! A breakthrough in technology at a breakthrough price.

The large numeric markers are luminescent and extremely easy to read so the watch is perfect for low light situation. The EMC^2 is water-resistant to 5 atms as well. The small readout shows you the date and has a digital second counter. This watch is rugged enough to take to the gym but handsome enough to wear to the boardroom or out to dinner. The designers built this watch for those who prefer their watches to be practical and sharp-looking rather than overrated and overpriced.

How can it be so accurate? The new F-1 clock uses laser beams to measure the photons emitted from the cesium atom to measure the resonance frequency. This laser-cooling clock makes it about 20 times more accurate than any other clock on earth.

This timepiece is a great gift for anyone who values precision and technology. Know precisely when the markets open and close. Know the times for landings and take offs or when the train is leaving the station. If punctuality and accuracy matter, then this watch was built for you.

We're still perfecting Einstein's theory. We must apologize that our Stauer EMC^2 Atomic Watch loses 1 second every 20,000,000 years. Our scientists are working diligently to correct this problem; but in the interim if you are not thrilled with the design and the accuracy of the EMC^2, return it in the next 30 days for a full refund of the purchase price.

This watch is not available in stores and it comes with our 30 day money-back guarantee. If you're not completely satisfied with the accuracy, simply return the watch for the full purchase price.

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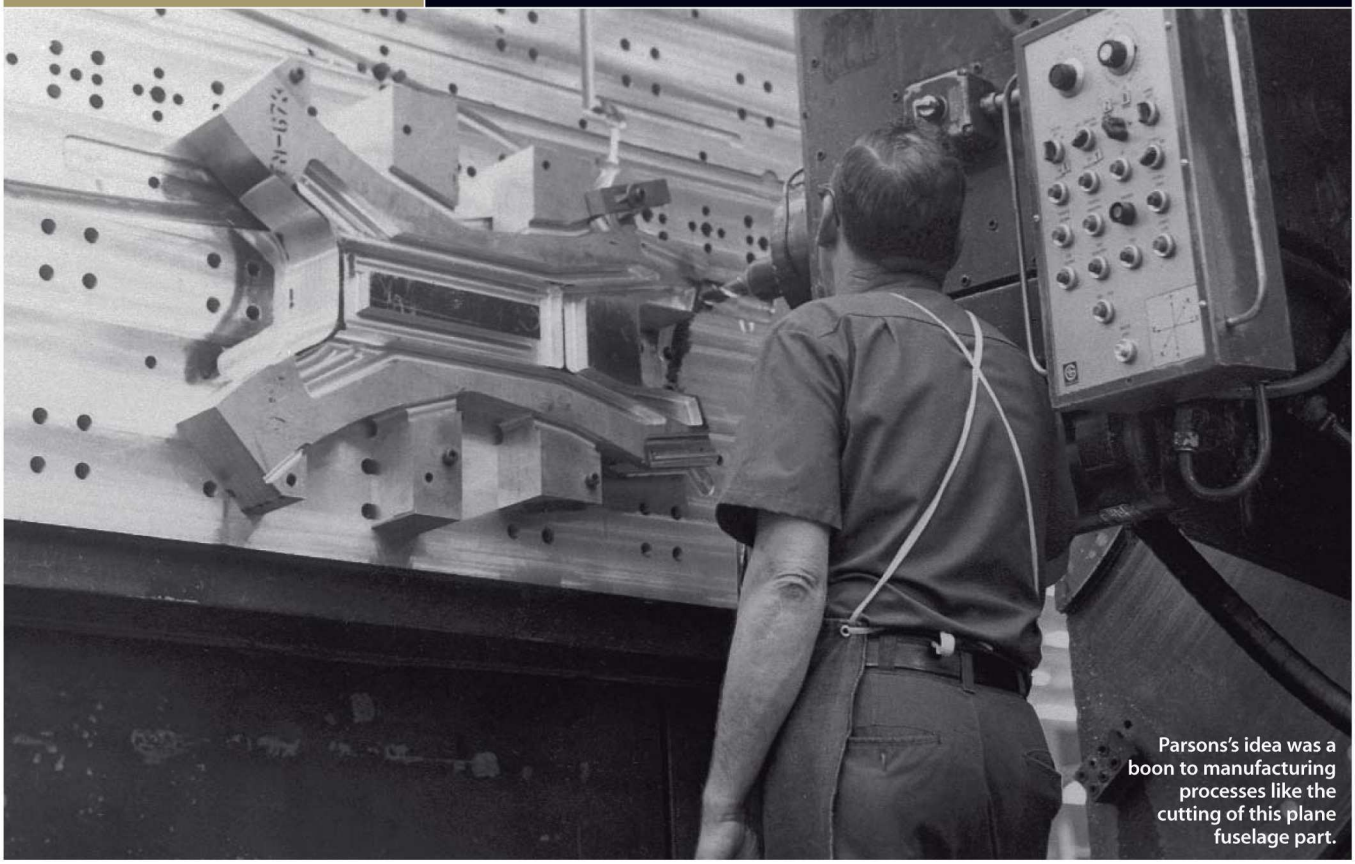

Parsons's idea was a boon to manufacturing processes like the cutting of this plane fuselage part.

Cut by Numbers

Using a punch-card calculator, John Parsons multiplied our manufacturing capabilities. **BY DAN CHO**

For decades, many of the most profound human innovations have demanded an inhuman precision. From contours that reduce a car's drag to the invisibly tiny features on a silicon chip, today's technological wonders would be impossible to fabricate using eyes and hands alone. Manufacturer John T. Parsons helped boost human production ability as a pioneer in computer-aided manufacturing. By translating machine motions into a set of numbers, Parsons taught machines to build machines.

In 1947, John Parsons headed the Parsons Corporation plant in Traverse City, MI, which produced helicopter rotors. At the time, digital computers were still gymnasium-sized affairs, but punch-card-operated electromechanical calculators were used by accountants. Parsons rented an IBM accounting machine to crunch some design parameters, since the shape of his rotor blades was defined by complicated equations. No one suspected that the machine would ultimately help Parsons produce finished parts with unprecedented accuracy and speed.

To make blade templates, workers had traditionally begun by marking 17 points that defined a template's curve—each laboriously calculated with a slide rule. They would then manually draw contours to connect the points, make a rough cutout of the shape, and file the piece down to specifications. Even with skilled workers, the process inevitably yielded errors that led to ruined templates and wasted time.

The IBM calculator, however, gave Parsons an idea. He asked employee Frank Stulen to compute 200 points along the edge of the contour, using the calculator. Parsons then had a machinist drill a hole at each of the 200 sets of coordinates. As the holes were now close enough to overlap, there was no need for additional tracing or cutting. All a machinist had to do was move the machining platform to the desired coordinates, drill a hole, move to the next coordinates, and repeat.

The technique still relied on a human to operate the machine, but Parsons envisioned the next step to automation—a motor-driven machine that was fed the numerical instructions via punch cards. Parsons took his idea to the U.S. Air Force, which granted him a contract but eventually gave control of the project to MIT. Nevertheless, today John Parsons is recognized as the father of "numerical control," and he was awarded the National Medal of Technology in 1985.

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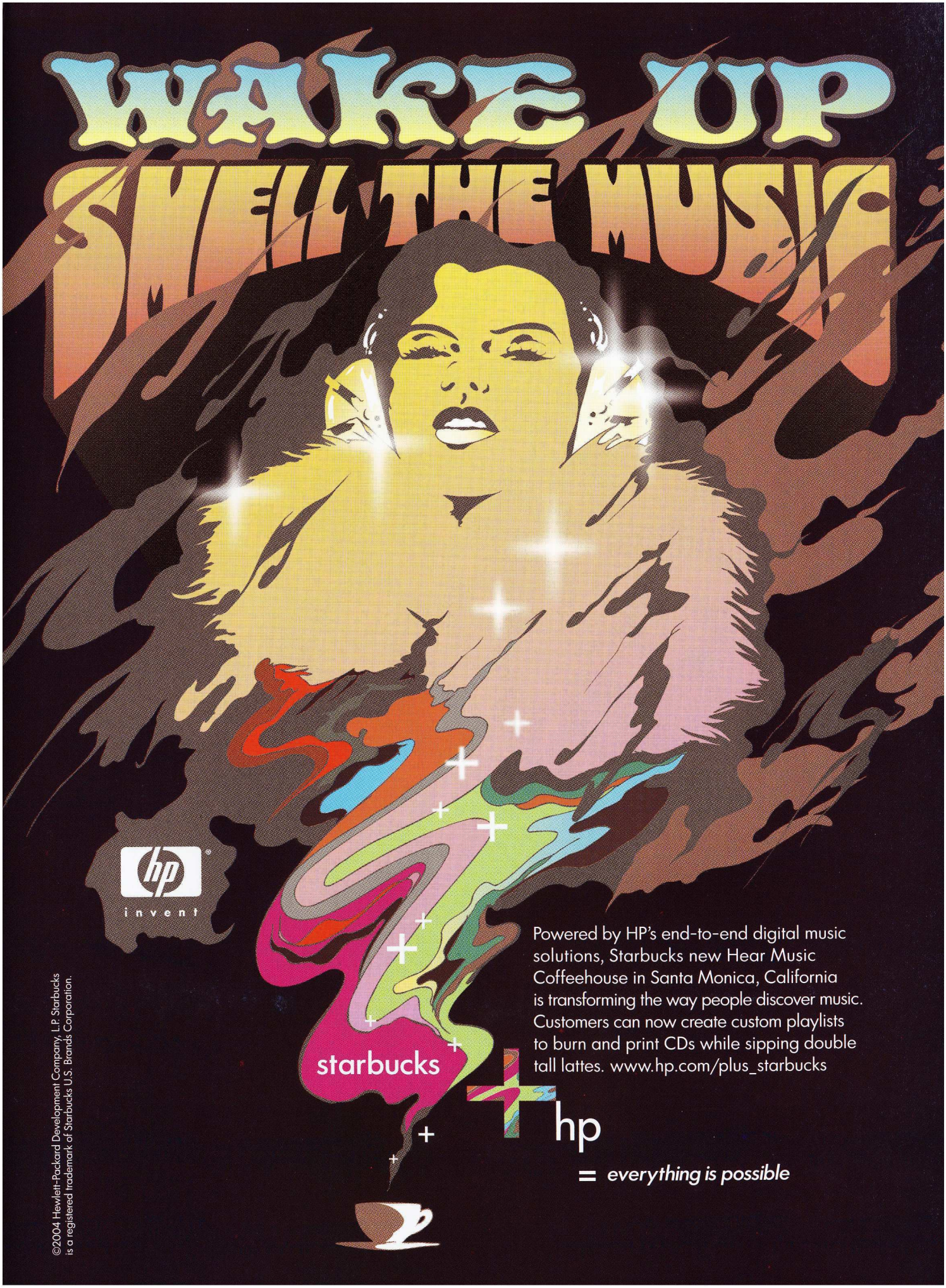
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